THESIS

THE AMPLITUDE AND DURATION OF EVOKED ACTION POTENTIALS IN HUMAN HAND MUSCLES IN HEALTH AND DISEASE

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INTRODUCTION

In the past decade, measurements of conduction velocity of the nerve impulse in motor nerves have assumed a major role in diagnostic electromyography. They are of especial value in the diagnosis and evaluation of neuropathy where characteristically conduction velocity is slow. Motor nerve stimulation has an advantage over sensory nerve stimulation in providing information about both muscle and nerve, instead of nerve alone. It is known (Hodes et al, 1948) that the amplitude of the evoked action potential recorded with surface electrodes over a muscle has a relationship to the number of active innervated muscle fibres. It is diminished in size in conditions which reduce this number, such as in partial denervation and in myopathy. However, it is also known (Eccles and O'Connor, 1924) that the amplitude of the evoked action potential varies with the position of the recording electrode, the highest negative action potential usually being recorded over the region of the end plates.

Although a few observations on this subject (Carpendale, Henriksen, Redford) have been recorded, there has been no systematic study of the amplitude and duration of the evoked muscle action potential and its relationship to position of recording electrodes on the surface of the skin overlying the contracting

muscle. Realizing that this could provide us with valuable information on the normal range of amplitude and duration in healthy subjects and form a base-line against which to compare results from patients with neuromuscular pathology, the present study was undertaken. In addition to providing new and basic information on the amplitude and duration of the evoked potential, it was decided to determine conduction times in proximal and distal nerve segments, because of the more accurate measurements of conduction distance in the terminal portion of the nerves which the present study allows.

REVIEW OF LITERATURE

Measurements of conduction velocity in nerves are more than 100 years old. In 1840 Johannes Muller speculated on the possibility of measuring the velocity of nervous action. Five years later duBois Raymond in Berlin outlined in formal terms the plan for such determination, and within six years (1851), Helmholtz, a pupil of Muller's succeeded in measuring the conduction velocity of the nervous impulse in a nerve muscle preparation. He stimulated the sciatic nerve of a frog at two sites, one close to the muscle, and the other at a distance from the muscle. The time taken from stimulus to muscle twitch was recorded for each point of stimulation. The time taken for the current to reach the muscle was called 'conduction time', and the difference in time between the near and far points of stimulation revealed the time required for the impulse to travel along the nerve from point to point. The distance between the two points (conduction distance) divided by the time gave the conduction velocity.

Clearly the technique of the nerve - muscle preparation was not feasible in human subjects. Therefore, Helmholtz devised a new procedure. This time he stimulated two sites on the skin overlying points on nerves which were at varying distances from the brain. Each time, the subject was stimulated by an induction shock produced when he pressed a key thus closing a galvanic circuit. The response of the subject was considered as the twitch response of the shock arrival which Helmholtz called 'psychic factors'. Difference in time between the two sites divided into the length of the sensory nerve gave the conduction velocity, which was calculated to be 62 metres per second.

Several other investigators (Hirsch, 1863; Schelske, 1864; Kohlrausch, 1866; and, von Wittich, 1868) used variations of this technique; the results varying from 34 to 94 metres per second. Later, Helmholtz and his pupil Baxt, after improving their apparatus, reported the first measurements of conduction velocity in human nerves (1870). They gave an average of 67 metres per second which is similar to results made withpresent day apparatus. These two investigators pointed out at that time the possibility of changes in conduction velocity with different temperatures.

In 1909 Piper, a young German physiologist, obtained electromyographic records of muscle contraction by means of a string galvanometer. For the first time the electrical action potential of the muscle, instead of the mechanical muscle twitch, was recorded with surface electrodes. His measured conduction velocity of 120 metres per second was greatly in excess of earlier results. Munnich in 1916 improved the method by adjusting the strength of the stimuli. In addition to this, he superimposed the action potential when stimulating the nerve at two sites. By

this means he ensured that the same nerve fibres were responding each time. He found the conduction velocity to be 66 metres per second.

However, the string galvanometer possessed considerable inertia, which resulted in too slow a response for a correct picture of the action potential, although this should not affect the accuracy of measurements of conduction timebetween two points.

The next step in improving the technique came in 1922 when Gasser and Erlanger introduced the use of the cathode ray oscilloscope for recording the action potential. In 1927 these authors reported that the conduction velocity in a nerve fibre is related to its diameter.

All the early studies were only of academic interest, but in 1948, Hodes, Larrabee, and German, reported the first significant clinical study of the conduction velocity of motor fibres in man. They used skin electrodes for stimulating and recording. The nerve was stimulated percutaneously and the time between the moment of stimulation of the nerve and the beginning of the muscle action potential was called 'latency of response'. This was recorded on a cathode ray oscilloscope and photographed. Conduction velocity was measured between two points on the nerves (elbow and wrist) for the ulnar and median, and at knee and ankle on the peroneal nerve. They observed that conduction time was larger in the terminal than in the proximal portion of the nerves due to two factors -

(a) slowing of the conduction velocity in the smaller terminal fibres of the nerve, and

(b) neuromuscular delay (interval between arrival of the impulse at the end plate, and beginning of the muscle

action potential). This factor was called 'Residual Latency'.

These authors found measurements of conduction velocity for healthy subjects varied from 46 to 67 metres per second for the ulnar, median, peroneal, and tibial nerve. They also described their method of measuring conduction velocity following nerve injury. Some of the patients were followed for 42 months. In measurements of conduction velocities about four months after injury, this value varied from five to fifteen percent of normal, and invariably improved up to forty percent of normal at a later date. They also showed that the conduction velocity reached sixty five to one hundred percent spontaneous recovery and not more than sixty five percent in nerves that had been sutured after the injury. Residual latency varied from 3.0 to 5.8 msec. Measurements were also made of amplitude and duration of evoked action potential, showing that amplitude was decreased and duration increased in denervated muscles, but these tended to return to normal in association with reinnervation. In healthy subjects, it was found that the average amplitude of the evoked potential from the abductor digiti quinti following stimulation of the ulnar nerve was 11.3 mv., and in the thenar muscles was 11.8 mv. after stimulating the median nerves.

Magladery, McDougal, and Stock reported in 1951 that ischaemia created a decreased conduction velocity in the nerve from 68 to 56 metres per second for the motor nerves, and from 55 to 36 metres per second in the afferent nerves.

Wagman and Lesse (1952) measured the conduction velocity of ulnar nerve in healthy subjects of different ages and found that

the conduction velocity was faster at the ages of four to five years of life.

In 1953, Norris, Shock and Wagman reported the gradual decrease in the donduction velocity of the ulnar nerve - an average of 0.2 metres per second for each year of age past thirty.

In 1956, Carpendale showed that in order to accurately measure residual latency it was important to have precise measurements of conduction distance as well as conduction time. To improve technique in measurements of conduction distance, he located the region of the end plate by finding the largest evoked negative potential from a number of surface recording positions. In using this technique he remarked on the large variation in amplitude with change of position of the recording electrode. Subsequently Henriksen, using a similar technique, measured some of the amplitudes, and showed variations from 1.0 to 10.8 millivolts.

Thomas (1958) reported conduction velocity of motor fibres of the ulnar nerve of infants and children. He made detailed measurements of amplitude and duration of evoked potential. The amplitude of the action potential of the hypothenar muscles following stimulation of the ulnar nerves, ranged from 1.6 to 6.7 mv. in the first few days of life, thus also being considerably lower than that of the normal adult - 5.0 to 20 mv.

The duration of the negative spike of the evoked potential from the hypothenar muscles ranged from 3.0 - 6.5 msec. on stimulation at elbow, while the duration of the positive peak was 4.2 to 9.6 msec. The values were smaller than those in the adult individual - 4.0 to 11.0 msec. - for the negative spike, and 7.0 to 14.0 msec. for the positive spike. Thomas also said that during

growth of infant and child, both mean duration and mean amplitude of the action potential, after a transient and questionably significant decline of the duration during the first year of life, increased and closely approximated adult values in mid to late childhood. Residual latency, this author reported, was shorter (mean 1.2 msec.) than in adults (mean 1.6 msec.). The residual latency reached adult values by the age of seven years.

In 1960 Christie and Coomes studied the normal variation of nerve conduction in the ulnar, median, and peroneal nerves, and concluded that measurements of latency are adequate for electro-diagnosis because measurements of conduction distance were unreliable.

In 1961 Skillan, Johnson, Hamwi, and Driskili reported slow conduction velocity in patients with diabetes mellitus.

In 1962 Johnson, studying conduction velocity of the ulnar nerve, found this to be slightly faster in the distal than in the proximal segments (the distal segment was measured from the elbow to the wrist, and the proximal from the axilla to the elbow).

From this literature one can appreciate the large amount of detailed study that has been done on measurements of conduction time, and conduction velocity in peripheral nerves. Improvements in technique have changed this procedure from an academic exercise in laboratory of Helmholtz to the reliable and reproducible clinical test of nervous function which it is today.

Although measurements of conduction velocity have become routine in most electromyographic laboratories, less work has been done on the parameters of amplitude and duration of the evoked potential, and its relationship to clinical work.

In 1941, Harvey and Masland used amplitude of evoked potential

from the hypothenar muscles following stimulation of the ulnar nerve in studies of myasthenia gravis. Later, Harvey, Kuffler, and Tredway (1945), used a similar technique in cases of peripheral neuritis and hysterical paralysis.

In 103 normal subjects (Lambert and co-workers), a single supramaximal stimulus to the ulnar nerve at the elbow evoked an action potential in the hypothenar muscles which had a mean amplitude of the negative spike of 11.4 mv. (range 5.6 to 20.8 mv.). These results are similar to those obtained by Hodes and associates (mean 11.3 mv., range 6 to 16 mv.), and Desmedt (mean 9.95 mv., range 7 to 15 mv.). However, they are significantly higher than those obtained by Botelho and associates (mean 7.7 mv.), and by Johns and co-workers (mean 7.5 mv.). Lambert suggests that these differences in results maybe related to positioning of the recording electrodes.

Buchthal and Pinelli (1953) studied the duration and amplitude of the action potential in muscular atrophy of neurogenic origin, and in patients with muscular dystrophy and polymyositis, using concentric needle electrodes. Johns, Grob, and Harvey (1956), studied neuromuscular function and the effects of nerve stimulation in normal subjects and in patients with myasthenia gravis. In this year Bergamini reported observations on the shape of the motor unit potential in muscular atrophies. In 1957, Buchthal, Guid, and Rosenfalck investigated the volume conduction of the spike of the motor unit potential using a new type of multi-electrode. Buchthal, Rosenfalck, and Erminio (1960) reported by means of multilead recordings, the territory and the number of muscle fibres per cross sectional area of motor unit (fibre density) in myopathies.

Using concentric needle electrodes, Saco, Buchthal, and

Rosenfalck (1962), studied motor unit potentials at different ages. They showed that duration of the action potential is shorter in infants than in adults. They explained this factor in terms of the increase in width of the end plate zone with growth in persons from 20 - 70 years. The potential with an initial delfexion was 2.3 times greater in the muscle abductor digitorum quinti than in the muscle biceps brachialis. These authors concluded that the increase of duration is attributed to an increased fibre density within the motor units caused by a decrease in the volume of the muscle.

REASONS FOR THE PRESENT STUDY.

Considering the data presented, it can be seen that studies of conduction time, conduction velocity, and residual latency, are of considerable value in diagnosis of lower motor neuron disorders. In addition to this, studies of the shape of the evoked potential following supramaximal nerve stimulation have been used by some authors, (Hodes, Lambert, etc.) as a measure of neuromuscular function, and they have shown the importance of the amplitude and duration of such action potential in the diagnosis of diseases of the motor unit.

However, some authors - Carpendale, Redford, and Henriksen have shown wide variations of amplitude and shape with change of position of recording electrodes in the same individual, and for this reason it was considered important to determine exactly what variations might occur in the shape of the evoked potential with change of position of the recording electrode in healthy subjects.

Therefore, the object of the present study was to map out over the surface of the hypothenar and thenar muscles various points

from which the action potential could be recorded, and study the changes in the shape and form of the potential using these different points as recording positions stimulating the nerve at the same level (above the elbow), and using the region of the maximal amplitude for all studies and measurements of conduction distance, time, and velocity. In addition to this and recording always from the position of highest action potential, hypothenar and thenar action potentials have been recorded simultaneously with two channels of the amplifier when stimulating the ulnar and median nerves at four points (axilla, above elbow, below elbow, and wrist) for the ulnar, and in three points (axilla, elbow, and wrist) for the median, in order to study conduction time and conduction velocity in each segment of these nerves.

As part of the above study, conduction time in the deep branch of the ulnar nerve and amplitude of the action potential of adductor pollicis have been measured.

II

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METHOD

A. General

The method used in the measurement of amplitude of muscle action potential and conduction time of the nerve impulse was similar to those described by Carpendale and Henriksen. A standard technique was used for marking out nine points over the thenar muscles from which the recordings were made. The median nerve was then stimulated at the elbow with a supramaximal square wave impulse. Resulting action potential from number one position of the recording electrode was displayed (Fig. 1) on a storage scope, and photographed from an oscilloscope, while being seen on a third monitor scope.

The same procedure was repeated after placing the recording electrode in each of the remaining eight positions.

The recording electrode was then replaced in the position which gave the highest action potential as shown on the storage scope, and further records were made with the nerve stimulated at the wrist, and occasionally at the axilla.

A similar procedure was adopted for the ulnar nerve and nine positions were marked out over the hypothenar muscles. The ulnar nerve was stimulated first at the elbow and after recordings from the nine standard positions had been made, was stimulated at the wrist, below elbow and axilla.

On twenty five healthy subjects simultaneous recordings were made from both thenar and hypothenar muscles when either nerve was stimulated, in order to detect any evidence of cross innervation. This was done in both arms for comparison.

A calibration pulse from two calibrators was used with each series of pictures, to ensure accuracy in measurement of amplitude.

A time line in milliseconds produced by a precise 1000 c/s timing oscillator was recorded on each picture inorder to determine conduction time.

Film of all recordings were enlarged 15 times and measurements of amplitude and duration of the muscle action potential as well as conduction time in the nerve were made.

B. Stimulation of the nerve.

A custom made Medelec* stimulator was used (Fig.1). This delivered simple monophasic rectangular pulses (rise time 5.0 microseconds) after passing through a step down isolation transformer. The transformer isolated the stimulating electrodes from the stimulator and its ground connections to reduce shock artefact.

The stimulating electrodes consisted of a pair of silver hemispheres 6.0 mm. in diameter, centered 2.0 cm. apart and connected to a handle by thick copper wire, which enabled them to be held firmly over the nerve.

The cathode was placed distally on the nerve and both stimulating electrodes adjusted until the maximum action potential was obtained with the least voltage.

The duration of the pulse was usually 0.1 milliseconds, occasionally increasing to 0.3 milliseconds or 1.0 milliseconds when stimulating the nerve in deep areas (ulnar below elbow, peroneal in fat people, etc.). The voltage of succesive pulses

* Medelec Ltd., Woking, Surrey, England.

was increased until a maximal action potential was obtained from the muscle. The voltage was then increased 30% supramaximal, thus ensuring stimulation of all motor fibres.

C. Recording evoked action potential.

A small silver recording electrode 6 mm. in diameter and 0.2 cm. deep filled with electrode jelly** was applied to the skin (Fig.1) over the area of the hypothenar or thenar, and held in position by adhesive tape. A reference or indifferent electrode similar to the recording one, was fixed in a similar manner over the tendinous insertion of the muscles at the base of the little finger and thumb.

The ground electrode, a rectangular lead plate 3.5 x 6.0 cm., was strapped on the dorsal aspect of the forearm.

Care was taken to clean the skin free of old electrode jelly prior to each recording.

Skin resistance varies quite markedly in different areas of the hand and with the degree of pressure applied on the electrodes. To study this problem measurements were made on five subjects with an Ohm meter (Hewlett Packard V.T.V.M. Model 410 B.).

The average of the five subjects skin resistances of the hand between two points separated 1.0 cm. apart, were as follows:

Dorsal aspect of the hand	10 megohms
Central aspect of the hand	10 megohms
Palmar aspect of the hand	8 megohms

With interposition of electrode jelly between these two

** E.K.G. Sol., Burton Parson & Co., Washington, D.C.

points over the surface of the skin, the resistance drops from:

Dorsal	10 megohms ..	to	..	3.4 megohms
Central	10 megohms ..	to	..	3.4 megohms
Palmar	8 megohms ..	to	..	4.0 megohms

The recording electrodes on the hypothenar and the recording electrodes on the thenar were each fed into a separate capacity coupled differential amplifier, and from this onto two separate beams on a custom made Medelec electromyograph. A third beam was used for a ruler type marker graduated in milliseconds.

The input impedance to the E.M.G. amplifier is 1.0 megohm, shunted by 150 micro micro farads. The low frequency time constant will be variable from 0.5 to 0.01 seconds. The high frequency cut off (-3db) will be variable from 300 c/s to 10 kc/s.

In the Medelec electromyograph (Fig.1) three oscilloscopes are connected in parallel. One of these acts as a display unit, the second monitor scope is synchronized with a Cossor 35 mm. Oscillograph Camera, and the third is a storage scope (Skiatron).

This arrangement has the following advantages:-

(1) Three beams allow for the simultaneous recording of evoked potentials from thenar and hypothenar muscles along with a time calibration. This was found essential in the critical measurement of amplitude because of the frequency with which the ulnar nerve may be inadvertently stimulated while stimulating the median nerve at the elbow. This produces a spuriously high evoked potential from the thenar muscles due to the additional evoked potential from the adductor pollicis. It is impossible to appreciate this error unless simultaneous recordings from both thenar and

hypothenar muscles are made.

(2) The storage scope permits superimposition of a series of records of stimuli and evoked potentials enabling one to ascertain that there is no variation in amplitude either due to technical faults or due to a myasthenic response. By superimposing evoked potentials with the same point of stimulation, but different positions of the recording electrode, the point at which the evoked potential arises is much easier to discern than from a single record. In addition to this it also greatly facilitates the identification of the highest action potential.

A large amount of data could therefore be collected on the storage scope and this then photographed with a Polaroid Land Camera.

D. Measurement of amplitude of action potential.

After the recordings had been made on a Kodak Panatomic X 35 mm. film, it was processed in a conventional manner, and the dry film enlarged 15 diameters to facilitate measurement. The amplitude of the action potential was measured (Fig.2) as the vertical distance from the base-line to the peak of the negative action potential. It was compared with the height of a rectangular wave calibration signal of known amplitude - usually 2.5 mv. put out by the Medelec electromyograph, after each recording. This was in turn compared with a Grass*** Square wave calibrator (Model SWC-1) to ensure accuracy.

E. Measurement of duration of action potential

Measurement of both the spike and the total duration of the

*** Grass Instrument Co., Quincy, Mass., U.S.A.

evoked action potential were made in the following manner (Fig.2):-

The spike duration is the time (msec.) from the beginning of the potential to the point where the descending limb of the negative deflexion intercepts the base-line.

The total duration is the time (msec.) from the beginning of the potential to the peak of the positive deflexion.

F. Measurement of conduction time.

Conduction time (Fig.2) was the time interval between the beginning of the stimulus artefact and the beginning of the first deflexion, positive or negative, of the evoked action potential. The distance between these twopoints on the record is compared with the distance along a ruler type time line with intervals of 1.0 msec., and thus conduction time can be read directly.

H. Special technique for marking skin and positioning of recording electrodes.

1. Hypothenar Muscles - Ulnar Nerve.

One line is drawn (Fig.3b) from the ulnar margin of the distal transverse palmar crease across the ulnar border of the hand and at right angles to the long axis of the 5th metacarpal.

A second line is drawn from the ulnar margin of the distal wrist crease across the ulnar border of the wrist and at right angles to the long axis of the forearm.

A third line is drawn at right angles to and joining the first two lines running along the middle of the ulnar border of the hand over the highest prominence of the hypothenar muscle, when

viewed along its long axis.

The distance along line three, between line one and line two, is measured. The middle point on this line is marked with a cross and is considered to be position one for recordings (the centre of the hypothenar muscle mass).

A rubber template is then centered over position one with its axis lying along line three. The template (Fig.3c) has nine holes each 0.6 cm. in diameter and separated from each other by 1.0 cm. Each of the nine holes is then marked out on the hand and used for positioning the recording electrode.

The indifferent electrode is placed over the insertion of the abductor digiti quinti, just proximal to the metacarpo-phalangeal crease on the ulnar border of the little finger.

2. Thenar Muscles - Median Nerve.

A line is drawn along the palmar aspect of the wrist crease (Fig.3a).

A second line is drawn across the palmar surface of the first metacarpophalangeal joint at right angles to the axis of the first metacarpal.

A third line connects the middle point of the 1st two lines. It runs along the middle of the long axis of the thenar muscles. The mid point of the third line is considered to be position ONE* for the thenar muscles, and the template is centered over it, with

* All further references to standard positions will be abbreviated thus - P. = position, followed by the number of the position, e.g. P.4 = standard position four.
Pos.Max = abbreviation for position from which maximum amplitude of evoked potential is recorded.

its axis lying along the third line. All nine positions are then marked out for the thenar muscles. Special attention was paid to the following when recording muscle action potentials:-

1. The stimulus must be supramaximal + 30% V.
2. There must be good contact between skin and electrode, and the patient must be well relaxed.
3. The ulnar nerve should not be stimulated at the same time as the median or vice versa, which can easily happen when stimulating a t the axilla, and occasionally occurs **when** at the elbow producing spuriously high results.

I. Temperature.

All the measurements were taken at room temperature 24° - 26° C.

J. Age and sex.

Subjects of both sexes were tested with ages varying from 15 months to 49 years, slightly more female subjects than male subjects.

K. Skin resistance.

It is well known that skin resistance is a factor in recording action potentials and therefore smaller amplitudes can be found in subjects with callous or thick skin.

Most of our subjects were students and none of them manual workers. Our recordings were taken without scratching the skin. In five cases scratches were made in each of the nine recording positions and changes of amplitude were found from 0 - 10% increase.

L. Reliability.

In order to determine how reproducible the results were, two subjects were tested by one examiner using the standard technique on different days over a period of six months. Variations which

might occur included those in a healthy subject, the apparatus, and in the technique used by the examiner.

M. Subjects.

This thesis includes only that group of subjects in which as far as we know, every technical error has been eliminated. The subjects were divided into the following groups:-

(a) Twenty five healthy subjects in which the amplitude and duration of the action potential was studied from nine different recording positions on hypothenar and thenar muscles when stimulating the ulnar and median nerve respectively in both arms. In this group the action potential was also recorded from the adductor pollicis and the conduction time in the deep branch of the ulnar nerve calculated.

(b) Twenty one healthy subjects in which conduction time and conduction velocity were studied in four different segments of the right ulnar nerve and two different segments of the right median nerve, when recording from the position of the highest action potential of the hypothenar and thenar muscles respectively.

(c) Twenty eight healthy subjects in which conduction velocity in the right and left ulnar nerve from elbow to wrist were compared. 'Residual latency' was also calculated in this group.

(d) Ten subjects with neuromuscular disorders have been included in the present thesis to demonstrate the difference from the healthy group.

III

RESULTS

Amplitude of Action Potential

Duration of Action Potential

Conduction Time in the Deep Branch of the Ulnar Nerve

Conduction Velocity and Residual Latency

Reliability.

RESULTS

AMPLITUDE OF ACTION POTENTIAL

A. Amplitude of action potential recorded from standard positions over hypothenar muscles following stimulation of ULNAR nerve.

1. Amplitude related to position of recording electrode.

In the right arm of twenty five healthy subjects following stimulation of the ulnar nerve at the elbow, the amplitude of the evoked potential from each of the standard positions on the hypothenar muscles varied from a low average of 7.19 mv. in P.4, to a high average of 10.36 ± 1.79 mv. in P.1 (Table I) (Fig. 4a).

Under identical conditions but in the left arm, the amplitude varied from a low of 7.15 mv. also in P.4, to a high of 10.44 ± 1.57 mv. again in P.1 (Table II) (Fig. 4a).

2. Frequency of recording highest amplitude from any one standard position.

In analysis of the results of amplitude related to position, it was found that in the right hypothenar the highest action potential was recorded (Table Vb) in 59.3% of subjects from P.1, 29.6% from P.3, and 11.1% from P.9 (Fig. 5a).

In the left hypothenar, 46.2% were recorded from P.1, 42.3% from P.3, 7.7% from P.8, and 3.8% from P.9 (Fig. 5a).

3. Comparison of amplitude of evoked potential from position one (P.1) with the highest action potential (Pos. Max.) from all standard positions.

Many electromyographers routinely record evoked potentials from

P.1. It has been shown that this is most commonly the position of the highest action potential, over the hypothenar muscles. However, it was considered important to know what error might occur if P.1 did not evoke the highest action potential. Therefore in those cases where P.1 did not evoke the highest action potential, the difference in amplitude between the evoked potential from P.1 and the highest action potential was calculated. In this same group of twenty five subjects, it was found that in the right arm of nine individuals, the position of maximum amplitude was not P.1, and that in one individual it was 77% more than the potential from P.1 (subject 7, Table I). The remainder varied from 0.7 to 31.4% (Table Vc).

In the left arm of thirteen subjects, the position of maximum amplitude was other than P.1. Here the differences were from 1.3 to 33.3% (Table Vc). The average difference for both right and left arms was 6.7%.

The Fisher "t" Test for P. and Pos. Max. was 1.17 for the right arm and 1.39 for the left arm. (P. = between .05 and .15).

4. Comparison of amplitude of evoked potential following stimulation at elbow and wrist.

It was also found that the amplitude of the evoked action potential of the hypothenar muscles was slightly smaller when stimulating the ulnar nerve above the elbow than when stimulating the nerve at the level of the wrist (Fig. 6a).

Average of the maximal amplitude of the evoked action potential shows that:

In the right hypothenar, the amplitude was 10.95 ± 1.61 mv. when stimulating the nerve at the elbow, while it was 11.08 ± 1.67 mv. when stimulating the nerve at the wrist.

In the left hypothenar, findings were of 11.06 ± 1.59 mv. and 11.31 ± 2.01 mv. respectively.

In stimulating the mediannerve above the elbow, however, the amplitude of evoked action potential from the thenar muscles was slightly larger than when stimulating at the wrist (Fig. 6b).

In the right thenar, the amplitude was 11.70 ± 2.01 mv. when stimulating at the elbow, while it was 10.60 ± 2.23 mv. when stimulating at the wrist.

In the left thenar, findings were 11.70 ± 2.24 mv. and 10.50 ± 2.04 mv. respectively.

B. Amplitude of action potential recorded from position one on thenar muscles (adductor pollicis) following stimulation of ULNAR nerve.

It is known that following stimulation of the ulnar nerve at elbow or wrist, an evoked potential can be recorded from over the thenar eminence as a result of the contraction of adductor pollicis. When making simultaneous recordings from hypothenar and thenar muscles, it became quite obvious that a spuriously large action potential from the thenar muscles can be recorded if both nerves are stimulated simultaneously, a not infrequent occurrence with stimulation at elbow.

To measure the size of the potential from the adductor pollicis, the electrodes were positioned as if in a routine recording from the thenar muscles following stimulation of the median nerve. However, the recording electrode was always over P.1 on the thenar. The ulnar nerve was stimulated at the elbow. The average action potential of 25 subjects was 5.0 mv. (range 2.8 - 7.8) in the right arm, and 4.52 mv. (range 1.2 - 8.6) in the left arm (Table VI).

C. Amplitude of action potential recorded from standard positions over thenar muscles following stimulation of the MEDIAN nerve.

1. Amplitude related to position of recording electrode.

In the right arm of the same group of subjects following stimulation of the median nerve at the elbow, the amplitude of the evoked potential from each of the standard positions on the thenar muscles varied (Table III) from a low average of 5.34 mv. in P.4, to a high average of 11.26 ± 2.21 mv. in P.1 (Fig. 4b). Under identical conditions but in the left arm, the amplitude varied from a low of 4.28 mv. also in P.4, to a high of 11.8 ± 2.53 mv. (Table IV) (Fig. 4b).

2. Frequency of recording highest amplitude from any one standard position.

In the results of amplitude related to position it was found that in the right thenar the highest action potential was recorded (Table V) in 73.1% of all subjects from P.1 and 26.9% from P.3

In the left thenar 48.2% were recorded from P.1, 44.4% from P.3, and 3.7% from P.2 (Fig. 5b).

3. Comparison of amplitude of evoked potential from P.1 with the highest action potential (Pos. Max) from all standard positions.

In this same group of twenty five subjects, it was found that in the right arm in four individuals, the position of maximum amplitude was not P.1, and that in one individual it was 37.5% more than the potential from P.1 (subject 21, Table III). The remainder varied from 11.6 to 25% difference (Table Vc).

In the left arm in twelve subjects, the position of maximum amplitude was other than P1. Here the differences were from 2.3 to 33.3% (Table Vc).

The average difference for both right and left arms was 0%.

The Fisher "t" Test for P.1 and Pos. Max. was 0.76 for the right arm and 1.15 for the left arm. (p = between .1 and .25).

DURATION OF ACTION POTENTIAL

A. Duration of action potential recorded from standard positions over hypothenar muscles following stimulation of the ULNAR nerve.

1. Duration of 'spike' potential related to position of recording electrodes.

In the right arm of twenty five healthy subjects following stimulation of the ulnar nerve at the elbow, the spike duration of the evoked potential from each of the standard positions on the hypothenar muscles varied from a short average of 5.66 msec. at P.3, to a long average of 6.35 msec. at P.5 (Table 7a).

Under similar conditions in the left arm, the spike duration varied from an average of 5.66 msec. at P.3, to 6.64 msec. at P.5 (Table 8a).

2. Duration of 'total' potential related to position of recording electrodes.

The total duration (from onset of action potential to maximum positive deflexion, Fig.2) was measured from the same records as the spike duration. In the right arm the total duration varied from an average of 8.54 msec. from P.3, to 8.84 msec. from P.8 (Table VIIb), while in the left arm it varied from 8.75 msec. at P.9 and P.3, to 8.91 msec. at P.2 (Table VIIIb).

B. Duration of action potential recorded from standard positions over thenar muscles following stimulation of MEDIAN nerve.

1. Duration of 'spike' potential related to position of recording electrodes.

In the same group of twenty five subjects following stimulation of the nerve at the elbow, the spike duration of the evoked potential

from each of the nine positions on the thenar muscles varied from a short average of 5.28 msec. at P.3, to a long average of 6.05 msec. at P.7 and P.9 (Table IXa).

Under similar conditions in the left arm, the spike duration varied from an average of 5.31 msec. at P.6 to 6.07 msec. at P.4 (Table Xa).

2. Duration of 'total' potential related to position of recording electrodes.

The total duration varied from an average of 8.60 msec. at P.3 to 8.84 msec. at P.9 (Table IXb), while in the left arm, it varied from 8.05 msec. at P.3 to 8.90 msec. at P4 (Table Xb).

CONDUCTION TIME IN THE DEEP BRANCH OF THE ULNAR NERVE

In a previous detailed study (Carpendale, 1956) on conduction time in the terminal portion of the ulnar nerve, all recordings were taken from the hypothenar muscles. This provides information about the superficial branch of the ulnar nerve, but none about the deep branch. The deep branch usually supplies all the interossei and the adductor pollicis, and is occasionally subject to comparison just distal to the point where it separates from the superficial branch. For this reason it was felt that studies of conduction time in this deep branch would be valuable in clinical work.

It was felt that measurements of conduction distance in the palm of the hand would be liable to error due to the tortuous path of the deep branch of the ulnar nerve. For this reason it was decided to express the findings as conduction time in the deep branch of the ulnar nerve minus the conduction time in the superificial branch of the ulnar nerve. By this means it does not matter at what point the nerve is stimulated proximal to the

wrist. Simultaneous recordings were made from Pos. Max. on the hypothenar and from standard P.1 over the thenar muscles, while stimulating the ulnar nerve at the wrist.

In twenty five healthy subjects the average conduction time between point of stimulation on the ulnar nerve at the wrist and evoked potential on hypothenar was in the right hand 2.33 msec. (range 2.0 - 3.2 msec.), and in the left hand 2.21 msec. (range 1.8 - 3.0 msec.).

In the same subjects the average conduction time from the same point of stimulation on the ulnar nerve to the evoked potential from adductor pollicis (P.1 - thenar) was in the right hand 2.83 msec. (range 2.5 - 3.5 msec.), and in the left hand 2.81 msec. (range 2.2 - 3.6 msec.).

Therefore the average difference in conduction time between point of stimulation on ulnar nerve at the wrist, to hypothenar, and point of stimulation to thenar, was in the right hand 0.50 ± 0.13 msec. (range 0.4 - 0.9 msec.), and in the left hand 0.60 ±0.16 msec. (range 0.3 - 0.8 msec.) (Table VI).

The Fisher "t" Test for both right and left arm was 0.5. The difference of means of both sides was not significant. (p = between 0.05 and 0.1).

CONDUCTION VELOCITY AND RESIDUAL LATENCY

Conduction velocity was calculated routinely between elbow and wrist, and the residual latency determined in ulnar and median nerves. Comparisons were made between:-

(1) right ulnar and left ulnar (group C)

(2) right ulnar and right median (group B)

In addition to these routine measurements, the conduction

velocity was determined in three segments of the right ulnar nerve, (axilla to above elbow, above elbow to below elbow, below elbow to wrist), and in two segments of the right median nerve, (axilla to elbow, and elbow to wrist) (group B). Comparisons were made between the conduction velocity in each of these segments and the routine measurement from above elbow to wrist.

These special studies were made because of a recent report, (Johnson, 1962), suggesting that conduction velocity in the forearm is faster than in the upper arm, and also because of the common finding of slowing in conduction velocity around the elbow in the tardy ulnar palsy. Therefore it was decided to determine whether any slowing occurred in healthy subjects around the elbow.

A. Routine conduction velocity and residual latency in ulnar nerve to hypothenar muscles.

In twenty eight healthy subjects (group C) the conduction velocity was measured by the routine technique (above elbow to wrist and recording electrode at Pos. Max. on hypothenar) in the right and left arm. The residual latency was also calculated in these subjects.

In the right arm the average conduction velocity was 64.2 metres per second (range 52.1 - 75.9). The average conduction time from wrist to hypothenar muscles was 2.54 msec. (range 1.6 - 3.0) over an average conduction distance of 5.44 cm. (range 2.8 - 7.0). The average residual latency was 1.72 msec. (range 1.21 - 2.38).

Under identical conditions but in the left arm, the average conduction velocity was 62.22 metres per second (range 43.3 - 73.7). The average conduction time from wrist to hypothenar muscles was 2.21 msec. (range 1.6 - 3.0), over an average conduction distance

of 5.53 cm. (range 2.8 - 8.4). The average residual latency was 1.60 msec. (range 0.83 - 2.10).

B. Comparison of rates of conduction velocity and residual latency by routine technique between right ulnar and right median nerves.

In another group (B) of twenty one healthy subjects, the conduction velocity was measured by the routine technique (above elbow to wrist and recording electrode on Pos. Max. on hypothenar or thenar) in the right ulnar and right median nerves. The residual latency was also calculated in these subjects.

In the right ulnar the average conduction velocity was 55.9 metres per second (range 47.5 - 67.0), and the average residual latency was 1.69 ± 0.35 msec. (range 0.92 - 2.31) (Table XIII).

Under similar conditions in the right median nerve, the average conduction velocity was 57.3 metres per second (range 48.9 - 66.1), and the average residual latency was 2.18 ± .48 msec. (range 1.61 - 3.13) (Table XIII).

The Fisher "t" Test comparison of residual latency for the right ulnar and right median nerve was 3.65 msec. (p = .0001).

C. Comparison of conduction velocities in different segments of the right ulnar nerve.

In the same subjects (group B), the conduction time and distance from Pos. Max. on hypothenar to points on the right ulnar nerve in the axilla, above the elbow, below the elbow, and at wrist, were recorded (Table XII).

From these measurements the conduction velocity for the ulnar nerve in the upper arm, at the elbow, and in the forearm, were calculated.

The average conduction velocity in the upper arm was 63.9

metres per second (range 44.0 - 78.5) S.D. 9.21 m/sec; at the elbow was 44.24 metres per second (range 32.1 - 61.1) S.D. 8.79 m/sec; and in the forearm was 61.1 metres per second (range 49.5 - 77.5) S.D. 7.29 m/sec. If the conduction velocity is calculated from above elbow to wrist (routine technique), the average for these subjects is 55.9 ± 5.36 metres per second (range 47.5 - 67.0) (Fig.7a).

D. Comparison of conduction velocities in upper arm and forearm of the right median nerve.

In the same group (B) of twenty one healthy subjects, the conduction time and distance from points on the right median nerve in the axilla, in the front of the elbow (antecubital fossa), and at wrist were recorded (Table XII).

From these measurements the conduction velocity for the median nerve in the upper arm, and in the forearm, were calculated.

The average conduction velocity in the upper arm was 67.0 metres per second (range 54.5 - 86.0), and in the forearm was 57.3 metres per second (range 48.9 - 66.1). The latter is also the velocity as calculated by routine technique (Fig. VIIb).

RELIABILITY

In one subject recording by standard technique from P.1 on ten different occasions, the mean amplitude was 8.75 mv, and varied from 8.12 to 9.3 mv, a variation of ± 6.75%. (Table XIV). In a second subject the mean amplitude from P.1 was 9.41 mv. and varied from 8.6 to 10.4 mv., a variation of ± 9.6%. In the same subjects the variation when recorded from Pos. Max. was ± 7.0% and ± 8.7% respectively.

IV

DISCUSSION.

Amplitude of evoked potential

Duration of evoked potential

Conduction time

Conduction velocity

Residual latency.

DISCUSSION

AMPLITUDE OF EVOKED POTENTIAL.

The amplitude of the evoked potential recorded from the hypothenar can be seen to vary from 3.0 to 14.0 mv., and in the thenar from 1.3 to 16.8 mv. In view of this large variation, it is important to consider those factors which may affect the measurement of amplitude of the evoked potential.

Major factors affecting amplitude arise from methods of stimulation, and recording, the reliability of the methods, and the state of health of the subject.

These factors will now each be considered in some detail.

Factors affecting measurements of amplitude of evoked potential.

A. Method of stimulation.

1. Variation of amplitude with strength of stimulus.

It is clear that if the stimulus to the nerve is subthreshold no action potential will be evoked; and conversely, if the stimulus is supramaximal, all the nerve fibres will be activated and these in turn will initiate contraction inall the muscle fibres which they supply provided that both nerve and muscle are healthy. If, however, the stimulus is not maximal, variations in amplitude will occur, and therefore it is essential to ensure the stimulus is 30 to 50% supramaximal. This is simply done by stimulating the nerve once per second while viewing the evoked potential on a storage scope (Skiatron), and gradually increasing the strength of the

stimulus. When the evoked potential no longer increases in amplitude, the stimulus is then increased 30 to 50% which should cause no variation in amplitude or shape of the evoked potential, and, therefore, it should result in an unchanging wave form.

The stimulus is, of course, only maximal for one given position of the stimulating electrodes. It is occasionally found that, even after the stimulus strength has been made supramaximal, a change in amplitude may be seen. This is most commonly due to movement of the stimulating electrodes which may slide off the nerve although their position on the overlying skin remains the same. This is a common occurrence in obese people, in people with laxity of the skin, and where the nerve is deeply situated, such as the median and ulnar nerve at the wrist, and peroneal nerve of the ankle. Flat and slightly concave, small (diameter 6.0 mm. or less) stimulating electrodes firmly attached to a good handle, have a definite advantage over spherical and large electrodes in retaining their position over the nerve. Occasionally it is necessary to have one operator using both hands to hold the stimulating electrodes securely over the nerve because of shifting electrode position with each muscle twitch.

2. Variation of amplitude with spread of stimulus to neighbouring nerves.

On occasions when the stimulus is increased in the supramaximal range one will find a further increase in amplitude. This is usually due to spread of the stimulus to a neighbouring nerve supplying muscles in the same region as the recording electrode. It is most commonly seen when stimulating the median nerve at axilla or elbow and recording from the thenar muscles. On

commencing stimulation, the stimulus affects only the median nerve, but as the stimulus increases it may spread to stimulate the ulnar nerve and as a result ulnar innervated muscles such as adductor pollicis, will produce an evoked potential. When recording from P.1 in the centre of the thenar muscles while stimulating the ulnar nerve, a large action potential up to 7.0 mv. can be recorded from adductor pollicis without any evoked potential arising from median innervated muscles. If when stimulating the median nerve the stimulus spreads to affect the ulnar nerve, a recording electrode placed over the thenar muscles will record both the action potential from adductor pollicis as well as that from the median innervated muscles on the thenar (i.e. abductor pollicis brevis, opponens pollicis, and flexor pollicis brevis). The evoked potential from these two groups of muscles will be summated and may be as large as 21.0 mv. It is, therefore, extremely important when stimulating the median nerves to bear this in mind. It is especially liable to occur in those cases where it is difficult to elicit a response due to some pathology e.g. carpal tunnel syndrome and the stimulus and duration are both increased to a maximal level. The stimulus then passing via the ulnar nerve and evoking a potential in the adductor pollicis is thought to be arising from the median innervated muscles of the thenar from which no response may be arising at all. If this is then reported as a normal result, the correct diagnosis may be completely missed.

The best method to ensure that such an error does not occur is to record simultaneously on two separate beams from both thenar and hypothenar muscles. Any spread of stimulus from one nerve to the other can readily be seen by an increase in evoked potential

from muscles supplied by the nerve which is not being directly stimulated. In our experiment, all recordings were made in this manner. An additional advantage of recording in this way is that cross innervation from median to ulnar and vice versa (a relatively common occurrence) can be easily detected. For example, if there is some cross innervation from the ulnar to the median in the forearm and one records simultaneously from both hypothenar and thenar muscles, the following patterns will be seen. While stimulating the ulnar at the elbow - a normal response may occur from the hypothenar - butan unusually large one from the thenar due to nerve fibres crossing from ulnar to median. However, on stimulating at the wrist, a normal response will be recorded from the hypothenar, but the large action potential from the thenar will be diminished - because those nerve fibres that crossed from ulnar to median in the forearm will not be affected when stimulating the ulnar at the wrist. When stimulating the median at the elbow, a small response will be recorded from thethenar and none from the hypothenar. But when stimulating the median nerve at the wrist, again no response will be recorded from the hypothenar, but a much larger response from the thenar. This is due to the fact that the median now has additional nerve fibres (and hence motor units) which have passed from the ulnar to the median in the forearm. Although this can be detected recording singly from thenar and hypothenar, diagnosis of cross innervation is much simpler and more accurate when recording from thenar and hypothenar simultaneously.

3. Variation of amplitude when stimulating at elbow and wrist.

From a theoretical view point one would expect the evoked potential following stimulation at the wrist to be slightly higher

in amplitude and shorter in duration, than when the same nerve is stimulated at the elbow. This is due to temporal dispersion of the impulse due to the different conduction velocities of nerves of different fibre diameter and has been demonstrated in the frog sciatic nerve (Gasser and Erlanger, 1927).

In comparing the evoked potential from the hypothenar following stimulation of the ulnar nerve, it can be seen that the amplitude following stimulation at the wrist is in 90% of cases slightly larger (average 0.11 mv. at the right hand and 0.25 mv. on the left), than the amplitude following stimulation of the ulnar nerve at the elbow (Fig. 6a).

However, in recording from the thenar following stimulation of the median nerve, the reverse occurs and the amplitude following stimulation at the wrist is lower (average 1.10 mv. on the right and 1.20 mv. on the left), than following stimulation at the elbow (Fig. 6b). There is no obvious explanation of this difference; however, it is possibly related to the fact that the median is more difficult to stimulate at the wrist than at the elbow, and at the elbow in spite of meticulous care it is difficult to avoid some spread of stimulation to the ulnar nerve, resulting in a slight additional evoked potential from the adductor pollicis. Spread of the stimulus from median to ulnar at the wrist is uncommon.

<u>B. Method of recording.</u>

<u>1. Time constant in amplification.</u>

If the time constant on the amplifier is short - as is often used in needle electrode electromyography - the amplitude of the action potential is cut short and therefore a true record is not obtained. It is important, therefore, that the time constant

should be long for all accurate recordings of amplitude. If the time constant is insufficiently long, distortion of a square wave signal is seen and this is useful as a check of adequacy of the time constant.

2. Recording electrodes.

(a) Intramuscular and surface electrodes, single and multiple.

There is a considerable difference in the results obtained with intramuscular and surface electrodes. To compare results of recording by these two methods, the following experiments were performed.

Using a monopolar needle electrode for recording and a surface electrode as the indifferent electrode, the action potential was 30 to 90% higher than with a surface electrode when recording from the centre of the muscle.

If the indifferent electrode was placed on the opposite side of the hand (e.g. recording needle electrode in the hypothenar and indifferent electrode on the standard position for that electrode when recording from the thenar muscles, or recording electrode in the thenar and indifferent electrode in the standard position for that electrode when recording from the hypothenar muscles) the amplitude drops about 1.5 to 2% compared with recordings made with the indifferent electrode located on the same side as the recording one. This difference was also observed in the same proportion when using a surface electrode instead of the needle as the recording contact.

The duration of the spike and total duration was 30% shorter recording with the needle electrode than with the surface electrode.

In addition to this, recordings were made using twelve

different electrodes - all of them 0.6 cm. in diameter, connected with a single lead and located over the region of the hand muscles innervated by the ulnar nerve, when stimulating this nerve at the elbow. Increase of amplitude occurred as each of these electrodes was eliminated, and the highest amplitude was for the single electrode located over the abductor digiti quinti muscle.

When a concentric needle electrode was used for recording, there was again an increase of amplitude of about 30% more than with the surface electrode, and a decrease in spike duration of about 30%.

From this one may conclude that recording with a needle electrode results in an increase of amplitude of the action potenial by 15 to 90%, and decrease in duration; but there is a large variation depending on the depth to which the needle is inserted into the muscle. Therefore no constant recordings can be made in this way.

The use of a surface electrode for recording from a given position on the skin over the muscle belly, and a similar electrode located over the tendinous insertion of the muscle to be tested, results in the most reproducible and reliable recordings of evoked potentials.

<u>(b) Effect of scratching skin beneath recording electrode.</u>

Skin resistance has an effect on the shape of the evoked potential, and to diminish this some workers routinely scratch the skin. To determine what effect this had, a routine recording was made from the nine standard positions, the skin was then scratched in each of the positions and then the recording repeated.

An increase of amplitude from 0 - 10% occurred after scratching

the skin, but there was no significant relationship to recording position.

(c) Effect of muscle size on amplitude of evoked potential.

Although difficult to quantitate, it was repeatedly observed that in normal muscles the more hypertrophied this was, the amplitude of the evoked potential was proportionately smaller. In general, therefore, children and young women have larger action potentials than strong athletic men.

Two factors may contribute to this:-

Firstly, increased skin resistance in the calloused hand of a labouring man - which as previously shown - may increase by 0 to 10% after scratching.

Secondly, Saco, Buchthal and Rosenfalck (1962), have shown that the duration of the action potential is shorter in infants than in adults. This is explained in terms of the increasing width of the end plate zone with growth. A similar process occurs with muscle hypertrophy. As amplitude usually falls when duration is increased (as on temporal dispersion) the hypertrophy of the muscle may be the cause of the decrease of amplitude seen in men as opposed to that in woman and children.

(d) Effect of position of recording electrode on amplitude.of evoked potential.

In recording from the nine standard positions on the hypothenar and thenar muscles, a three dimensional amplitude - space histogram can be drawn for each muscle. From the average of many subjects (Fig. 4a and 4b) it can be seen that P.1 is usually the largest and P.4 usually the smallest. This is true for both hypothenar and thenar muscles following stimulation of the ulnar and median

nerve respectively. In the histogram of the amplitude recorded from the hypothenar, the column in P.1 (central on the muscle belly and region of end plate) is largest and the columns decrease in height around it. However, it should be remarked that the decrease in amplitude is more marked for positions located in the palmar portion of the hand No.4 - 2 - 7, than for the positions located on the dorsal part No. 6 - 3 - 9, in which No.3. especially is often the position of highest amplitude.

This phenonmenon is well repeated in the four nerves studies. When a hand is dissected it can be seen that the skin in the palmar surface is considerably thicker due to a large amount of fibro-fatty tissue than the skin on the dorsal surface, which is very thin.

If tissue is a volume conductor and skin is a resistance medium, it could be an explantation of the foregoing results.

In cases where the largest action potential happens to be in a position other than P.1, a number of explanations are possible.

(1) The end plate zone for these subjects is located in a position other than P.1 and corresponding to the position of maximum amplitude.

(2) The resistance of the volume conductor in between the end plate zone and recording area is smaller in the position from which maximum amplitude is recorded than for these subjects.

(3) The action potential is picked up from the fourth interosseus muscle and the action potential from the hypothenar muscles are thereby potentiated.

(e) Comparison of amplitude of evoked potential recorded by different authors.

Eccles and O'Connor (1939) have shown by recording the evoked potential from different points of the muscle belly that the region of the end plate gave the highest initial deflexion and this was always negative.

Both Carpendale (1956) and Reford (1956) showed that in the human arm and hand muscles, this region is usually over the most prominent point in the middle of the muscle belly.

In our results in different groups of subjects in 40 to 60% of the cases for the hypothenar and 52 to 65% for the thenar area, the highest action potential was recorded from P.1 in the centre of the muscle belly, but in the remainder, the maximal amplitude was recorded from some other positions in the recording areas.

Dissection of the small muscles of the hands of ten cadavers (Fig. 8a, 8b, 8c, 8d) indicate that the smallest branches of the ulnar and median nerves terminate near the middle of the hypothenar and thenar muscles respectively, close to P.1.

Our results show an average increase of 0.59 and 0.64 mv. for the right and left hypothenar, and 0.44 and 0.70 mv. for the right and left thenar, when recording from the position of the highest action potential compared with recordings taken from the centre of the muscle.

This is an error of only 4.4% to 7% (difference of the means not significant - p = between 0.05 and 0.25), when studying average results of groups of healthy subjects, but when studying one subject variation of amplitude from the P.1 (centre of the muscle belly) and position of the highest action potential was found to be 2 to 4 mv., for the amplitudes of 10 to 12 mv.

In these cases the error is 20 to 33%, and this is of considerable importance in studying patients, especially when diagnosis of disease is doubtful.

Studies in each individual subject to localize the position of the maximal amplitude are therefore of considerable value in electrodiagnosis.

In these results we also see that in recording from any point on the hypothenar or thenar the amplitude of the evoked potential may vary between 3.0 and 14.0 mv. on the hypothenar, and from 1.3 to 16.8 mv. on the thenar. Whereas the range of variation for the position of the highest action potential is only 7.9 mv. to 14.0 mv. for the hypothenar, and 5.8 mv. to 16.8 mv. for the thenar. It is clear that a smaller range of variation occurs when recording from the position of maximum amplitude.

The results recorded from the position of maximum amplitude are similar to those results (mean and variation) reported by Lambert et al (1960), Hodes et al (1948), and Desmedt (1958); however, they are significantly greater than those reported by Botelho and co-workers (1952) (mean 7.7 ± 0.49 mv.) and Johns and associates (1956) (mean 7.5 ± 0.55 mv).

The good correlation of results with Lambert and co-workers (1960) is probably due to the fact that they recorded from the centre of the muscle belly (i.e. on P.1). Hodes and associates (1948) took pains to find the position of maximum amplitude before recording. The much smaller mean amplitudes recorded by Botelho and co-workers (1952) and Johns and associates (1956), may be due to any of the factors already discussed; but the most probable is due to the recording electrode not being positioned in the centre of the muscle belly.

C. Reliability of method in measurement of amplitude of evoked potential.

In recording from the same subject on different days (Table XIII) variations up to ± 9.6% in amplitude of evoked potential occurred. This suggests that variations on different occasions greater than ± 10% may be important in the diagnosis of neuromuscular pathology.

D. Amplitude of evoked potential in patients with neuromuscular disorders.

The main purpose of the present study was to establish a normal range of amplitude of evoked potential in healthy subjects to act as a base-line against which to compare the results from patients with neuromuscular disorders. In addition to all the healthy subjects, six patients with polyneuritis and seven patients with muscular dystrophy were examined in the same detailed manner. The results show (Fig. 9) clearly the marked decrease in amplitude that occurs with either decreased number of motor units (polyneuritis), or decreased number of muscle fibres but a normal nerve supply (muscular dystrophy). For neuromuscular disorders affecting the small muscles of the hand the amplitude of the evoked potential recorded by the present method, provides a most valuable objective, and reproducible test for both diagnosis and follow up.

DURATION OF EVOKED POTENTIAL

The significance of the duration of the action potential when recorded from surface electrodes is open to considerable debate.

The results obtained in the present study suggest a number of conclusions.

1. Duration of evoked potential following stimulation of nerve at elbow and wrist.

Duration (both spike and total) recorded from the position of the highest action potential is a fraction shorter when stimulation was applied at the wrist than when stimulated at the elbow (Fig. 6a, 6b). In twenty five subjects the average difference varies from 0.10 to 0.41 msec. This can also be explained by the larger temporal dispersion of the nerve impulse during its course from elbow to hand as compared with its course from wrist to hand (Gasser and Erlanger, 1927).

2. Duration of evoked potential related to length of muscle fibre.

The duration of the action potential appears to bear a definite relationship to the length of the muscle fibre. In order to determine what this was, the following experiments were undertaken.

(a) A recording electrode was located over the position of largest amplitude action potential of the adductor of the thumb when the ulnar nerve was stimulated at the elbow. The hand was in the relaxed neutral position. A trace of an action potential was drawn on the Skiatron. Following this and with stimulation and recording electrodes in the same place, the thumb was abducted as far as possible, and both it and the wrist fixed in a splint which allowed no movement and therefore only an isometric contraction. The duration of the action potential, both spike and total duration, increased to one msec. (Fig. 10a).

(b) This time it was decided to produce a larger contraction of the muscle fibres by stimulating more frequently.

The ulnar nerve was stimulated at frequencies of one per second at the elbow when recording the action potential from the position of the maximal amplitude in the hypothenar. A trace of the action potential was drawn on the Skiatron. The stimulator frequency was then cncreased to three per second, and a further one second trace superimposed on the previous record. No changes in amplitude or duration of the action potential were seen.

Next time, the stimulator frequency was increased to ten per second, and another one second trace superimposed on the previous record. On this occasion the duration of the action potential was diminished by 0.75 msec., and the amplitude by 0.75 mv.

Once more the stimulator frequency was increased to thirty per second, and the traces were superimposed for about two seconds in which time we believe there was no fatigue at the junction of the muscle fibres. This time the duration of the action potential decreased by 1.0 msec., and the amplitude by 1.0 mv.

The superimposed photograph (Fig. 10b) taken from the Skiatron tube illustrates these factors.

One may deduce from these experiments that the duration of the evoked potential increases when the muscle is stretched, and decreases when the muscle is in a contracted state.

3. Duration of evoked potential related to position of recording electrodes.

The duration of the evoked potential is shortened when recorded from the position of highest amplitude. In other standard positions

the spike duration is 0.1 to 0.3 msec. larger, but the total duration may be 4 to 5 msec. larger.

4. Comparison of spike and total duration of evoked potential.

Spike duration shows relatively little variation when recorded from the nine standard positions whereas the total duration shows very marked variation as noted. This is due to the fact that measurement of total duration is much more difficult because of uncertainty of the position of the peak of the positive wave. Measurements of spike duration may also be difficult unless recorded from the positions of maximum amplitude. If measured in this position, spike duration is a reliable and reproducible parameter.

CONDUCTION TIME

Conduction time as a parameter in peripheral nerve stimulation has been well studied by several authors - Carpendale, Redford and Henriksen.

As these authors point out there is still an error in measurements of 0.1 to 0.4 msec., due to difficulties in knowing the exact point of origin of the negative deflexion, especially if this has not been recorded from the region of the largest potential. Thepresent studies of conduction time for each of the nine positions show NO significant differences compared with the position of the highest amplitude. This can be easily demonstrated by superimposing on the Skiatron (Fig. 11) traces recorded from each of the nine standard positions. Positive and negative deflexions at the start of the evoked potential all arise at the same point on the tracing.

The present studies also confirm the fact that conduction time in the terminal portion (wrist to thenar) of the median nerve is

prolonged (average 0.5 msec.), compared to the same distance (wrist to hypothenar) for the ulnar nerve. This was tested statistically in terms of residual latency (see Page 24).

CONDUCTION VELOCITY

Although measurement of conduction velocity was not the primary purpose of this study, it was felt that in view of the special technique of recording from nine standard positions that a high degree of accuracy should be possible and would be useful for comparison with earlier work.

The results of average conduction velocity for ulnar and median nerves (average of all subjects) agree well with those of other workers - Hodes et al (1948), Carpendale (1956), Henriksen (1956), and Redford (1958).

However, when a comparison was made between proximal and distal segments in the nerve, a new factor was observed. Realising that slowing of conduction is apparent in the median nerve while traversing the carpal tunnel even in healthy subjects, it was thought that the same effect might be found in the ulnar nerve as it crossed the medial epicondyle where the first signs of tardy ulnar palsy are manifest. Accordingly, the ulnar nerve was stimulated at four points (axilla, above elbow, below elbow, and wrist), and the conduction velocity calculated for each segment of upper arm (axilla to above elbow), across the medial epicondyle (above to below elbow) and in the forearm (below elbow to wrist). In addition to these, the usual conduction velocity from above elbow to wrist was calculated.

The results in the right ulnar nerve were as follows:-

1. Right ulnar - hypothenar muscles

Segment - Axilla to elbow - C.V. average 65.30 ± 9.31 metres/sec. - range (78.5 - 44.0)

Segment - above elbow to below elbow - C.V. average 44.0 ± 8.79 metres/sec. - range (61.1 - 32.1).

Segment - above elbow to wrist - C.V. average 56.80 ± 5.36 metres/sec. range (67.0 - 58.9)

Segment - below elbow to wrist - C.V. average 61.23 ± 7.29 metres/sec. range (77.5 - 49.5)

These results show clearly three important factors in conduction velocity along the ulnar nerve (Fig. 7a).

(i) Conduction velocity is faster in the proximal segment (upper arm) of the nerve than in the distal segment (forearm).

(ii) Conduction velocity (above) elbow to wrist is slower than from (below) elbow to wrist.

(iii) Conduction velocity across medial epicondyle (above elbow to below elbow) is much slower than any other portion of the nerve. The difference of the means of two portions was highly significant (p = less than 0.00005).

This slowing in conduction velocity at the level of the medial epicondyle suggests that there may be compression of the ulnar nerve at this site even in healthy subjects, as also probably occurs in the median nerve in the carpal tunnel.

2. Right median - thenar muscles.

Similar studies were taken for the median nerve in the same group of subjects. In this group only the portions of the axilla - elbow and elbow - wrist were considered.

The results in the right median nerve were as follows (Fig.7b):-

Segment - axilla - elbow C.V. average 66.2 metres/sec. - range (82.8 - 54.5)

Segment - elbow - wrist C.V. average 58.4 metres/sec. - range (68.1 - 48.9)

Once more the conduction velocity for the proximal portion of the nerve is faster than for the distal portion of the nerve.

These results agree with the majority of other studies where conduction velocity in the proximal segment is slightly faster than in the distal segment.

However, they disagree with one study (Spiegel and Johnson, 1962) where in the ulnar nerve the mean proximal velocity was 60.3 metres per second, and the mean distal velocity was 63.2 metres per second i.e. 2.9 metres per second faster than the proximal velocity. These authors have no explanation for their findings, but the present study suggests that it would be possible to produce such results in the following manner. If the ulnar nerve were stimulated at three points (axilla, below elbow, and wrist), and the conduction velocities then calculated for upper arm and forearm - the slow conduction time across the medial epicondyle would be included in the upper arm conduction velocity which might then be slower than the conduction velocity in the forearm.

RESIDUAL LATENCY

All measurements of residual latency were calculated from measurements of conduction time and distance to the position of recording maximum amplitude of evoked potential.

The mean of the residual latency for the right ulnar nerve

was 1.62 ± 0.35 msec. (range 0.92 - 2.31 msec.), and for the right median nerve 2.20 ± 0.48 msec. (range 1.61 - 3.13 msec.). These are similar to those of Carpendale (1956) who found a mean of 1.4 msec. (range 0.9 - 1.8 msec.) for the ulnar nerve, and 2.20 msec. (range 1.4 - 3.1 msec.) for the median nerve. The difference of the means of the residual latency was highly significant for these two nerves (p = less than 0.0001).

Both of these results confirm the contention that there is slowing in the terminal segment of the median nerve compared with the ulnar nerve probably related to passage through the carpal tunnel.

V.

SUMMARY.

1. A standard method has been devised for marking the skin over the hypothenar and thenar eminences for positioning electrodes to record the evoked potential from the underlying muscles following stimulation of the ulnar and median nerves respectively.

2. Nine positions, each 10 mm. apart in the shape of a square, one marked on the skin over both the hypothenar and thenar muscles and the central position (P.1) is so located that it coincides with the position of termination of the small nerves supplying each of these muscles. This has been confirmed by careful anatomical dissection.

3. Recordings have been made of the evoked potential following stimulation of the ulnar and median nerves at the elbow and wrist in twenty five healthy subjects.

4. The amplitude and duration (spike and total) of the evoked potential recorded from each of the positions on both hands has been measured. On the hypothenar muscles following stimulation of the ulnar nerve at the elbow, the highest amplitude is most frequently recorded from position one, and next most frequently from position three. From these two positions together, the highest evoked potential was recorded in more than 80% of subjects. The average amplitude recorded from position of highest action potential was 11.1 $\pm$ 1.6 mv.

(range 7.9 - 14.0 mv.). The average duration determined from the same position for spike duration was 5.87 msec., and for total duration was 8.68 msec. The amplitude of the evoked potential recorded from the other positions may be less than half the amplitude of the maximum potential. Correct positioning of recording electrodes is therefore essential for recording the highest action potential and also for reproducibility of results.

5. On the thenar muscles following stimulation of the median nerve at the elbow, the highest action potential was again recorded most frequently from position one and next most frequently from position three. From these two positions, the highest evoked potential was recorded in over 90% of all subjects. The average amplitude from the position of the highest action potential was 11.70 $\pm$ 2.3 mv. (range 5.8 - 16.8 mv.). The average duration from the same position for spike duration was 5.40 msec. and for total duration was 8.40 msec. Here also it was found that the amplitude of the evoked potential recorded from positions other than that of maximum amplitude sometimes were less than half this amplitude, again emphasizing the importance of correct and standardized positioning of the recording electrodes.

6. Conduction time was calculated for the deep branch of the ulnar nerve and was found to be an average 0.55 to 0.60 $\pm$ 0.14 msec. longer than the conduction time from wrist to hypothenar.

7. The conduction velocity was calculated for the ulnar nerve in

different segments of the right arm in twenty one healthy subjects. In the upper arm the average conduction velocity was 63.9 ± 9.21 metres per second, which was slightly faster than in the forearm (61.6 ± 7.29 metres per second), but both were much faster than the conduction velocity in the region of the elbow (44.24 ± 8.79 metres per second). There was a statistically significant difference between the mean conduction velocity in the forearm and across the elbow ($p = 0.00005$). This suggests that even in healthy subjects there is some compression of the ulnar nerve at the elbow.

8. Conduction velocities and residual latencies were also calculated for both median and ulnar nerves and found to agree well with other authors. However, in the median nerve the mean residual latency was 2.18 ± 0.48 msec., which was larger than that in the ulnar nerve 1.69 ± 0.35 msec. ($p = 0.0001$). This suggests that even in healthy subjects there is some narrowing of the median nerve within the carpal tunnel.

9. Seven patients with muscular dystrophy and six patients with polyneuritis were examined by this standard method, and clearly illustrates the marked decline in amplitude in these conditions and the value of this test in the diagnosis of neurological disorders.

VI

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VII

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TABLE I

*Amplitude of evoked potential recorded from nine standard positions on Hypothenar muscle following stimulation of the (R) Ulnar Nerve

25 Healthy Subjects

Subject	Sex	Age	Position of Recording Electrode 1	2	3	4	5	6	7	8	9	***Max.Amp.Pot. Elbow	Wrist
M.	F.	19	13.2	9.3	10.8	9.2	10.6	7.9	7.8	7.0	8.4	13.2	12.7
P.	F.	36	10.3	7.7	11.2	7.8	9.7	9.8	7.4	7.8	9.4	11.2	12.0
L.	M.	44	7.9	5.6	6.6	6.0	6.6	7.1	4.2	5.7	5.9	7.9	7.8
C.	M.	38	10.6	9.3	9.8	10.0	9.8	9.2	7.8	9.1	10.3	10.6	11.6
Z.	M.	48	9.0	6.4	9.7	6.0	5.8	5.0	5.2	5.1	6.9	9.7	9.1
C.	F.	22	10.0	9.2	7.6	7.0	7.0	7.0	4.4	4.2	4.5	10.0	10.0
M.	F.	18	7.8	6.4	8.5	4.4	6.2	7.7	11.6	13.1	13.8	13.8	14.4
B.	M.	30	10.0	7.5	8.9	8.0	8.5	8.8	6.8	7.9	8.2	10.0	9.8
R.	F.	24	11.8	9.5	11.4	7.5	8.0	9.0	8.1	7.8	8.0	11.8	11.2
D.	F.	20	10.4	7.8	10.4	7.8	7.8	8.2	5.5	6.2	7.8	10.4	9.0
G.	F.	20	13.0	9.8	9.9	9.8	10.4	9.8	7.4	7.0	6.1	13.0	12.6
A.	F.	23	9.6	6.4	9.0	7.1	7.4	7.5	8.3	8.5	9.8	9.8	9.8
S.	M.	24	10.2	7.4	10.0	4.2	4.7	6.1	8.4	9.4	9.2	10.2	11.5
S.	F.	21	13.5	10.4	11.1	8.8	8.1	9.5	9.1	10.7	8.6	13.5	14.0
E.	F.	20	10.2	8.1	11.0	7.0	8.2	8.1	9.4	10.2	9.8	11.0	11.8
P.	F.	19	10.2	8.0	12.0	6.7	7.9	8.0	7.8	9.3	10.0	12.0	11.8
E.	F.	20	11.5	8.5	11.5	9.0	10.0	11.1	6.2	7.6	8.5	11.5	10.9
L.	F.	19	13.7	10.4	13.8	10.0	11.8	12.1	11.0	12.1	12.0	13.8	12.4
B.	M.	28	8.5	6.2	7.6	5.6	6.3	6.3	4.7	5.2	5.8	8.5	8.3
G.	F.	23	8.1	7.2	9.6	5.2	6.8	8.3	6.7	6.9	7.4	9.6	10.8
B.	M.	23	11.0	8.1	9.7	8.3	9.0	10.8	7.9	9.4	9.0	11.0	12.8
K.	M.	19	11.1	7.1	9.6	6.9	6.8	6.2	7.0	7.8	8.7	11.1	11.5
J.	M.	36	9.5	6.9	8.3	5.4	7.4	7.4	6.0	6.6	6.3	9.5	10.0
K.	M.	26	11.2	10.4	11.0	6.4	10.0	8.8	6.0	5.1	4.1	11.2	11.1
M.	M.	31	7.0	6.0	7.4	5.7	4.4	4.7	6.9	7.9	9.2	9.2	9.3
Total			259.3	199.6	246.4	179.8	199.2	204.4	181.6	197.6	207.7	273.5	276.2
Average			10.36	7.98	9.86	7.19	7.97	8.18	7.26	7.90	8.31	10.95	11.06
Range			(7.0-13.7)	(5.6-10.4)	(6.6-13.8)	(4.2-10.0)	(4.7-11.8)	(4.7-12.1)	(4.2-11.6)	(4.2-13.1)	(4.1-13.8)	(7.9-13.7)	(7.8-14.4)

*Amplitude of evoked potential is measured from the base line to the peak of the negative deflection. (Fig.2).

***Max.Amp.Pot. is the amplitude of the highest action potential recorded from nine standard positions.

TABLE II

*Amplitude of evoked potential recorded from nine standard positions on Hypothenar muscle following stimulation of the (L) Ulnar Nerve

25 Healthy Subjects

Subject	Sex	Age	Position of Recording Electrode 1	2	3	4	5	6	7	8	9	***Max.Amp.Pot. Elbow	Wrist
M.	F.	19	12.2	9.9	9.7	9.7	11.2	8.9	6.5	5.7	5.8	12.2	12.7
P.	F.	36	11.7	10.1	12.7	9.3	11.7	12.0	8.0	10.0	11.6	12.7	14.6
L.	M.	44	10.1	6.7	10.3	6.8	7.6	7.6	7.3	8.4	6.9	10.3	9.5
C.	M.	38	12.4	11.0	14.0	12.7	10.4	11.0	9.8	13.4	12.5	14.0	14.7
Z.	M.	48	8.8	6.9	10.5	7.4	7.4	5.0	4.7	5.5	5.6	10.5	10.3
C.	F.	22	10.0	7.4	9.0	7.7	8.8	9.0	3.8	5.3	5.5	10.0	9.3
M.	F.	18	11.6	10.8	14.0	10.7	10.8	11.4	10.7	10.5	11.6	14.0	14.3
B.	M.	30	11.1	7.4	10.2	7.9	8.4	8.7	7.0	8.2	8.2	11.1	9.0
R.	F.	24	10.4	6.8	9.8	5.8	9.4	9.5	7.5	9.7	6.5	10.4	11.8
D.	F.	20	9.6	7.8	10.4	7.1	7.3	7.3	7.0	6.6	8.2	10.4	7.8
G.	F.	20	11.4	10.5	9.0	9.3	10.2	9.0	10.8	10.1	6.2	11.4	11.0
A.	F.	23	8.8	6.8	8.5	4.2	5.0	5.5	8.2	9.2	9.2	9.2	9.5
S.	M.	24	12.4	10.5	13.4	6.5	8.9	10.4	11.0	10.3	9.5	13.4	14.3
S.	F.	21	12.7	8.2	9.5	7.3	6.2	8.4	7.1	8.9	7.8	12.7	11.1
E.	F.	20	8.8	7.0	9.0	4.1	4.4	6.1	7.8	8.2	7.8	9.0	12.0
P.	F.	19	11.6	7.7	10.5	5.7	9.2	10.0	8.2	9.3	9.7	11.6	12.9
E.	F.	20	12.0	6.4	11.7	7.8	10.1	10.1	6.9	7.4	8.9	12.0	10.4
L.	F.	19	11.5	11.8	13.0	8.1	11.1	9.0	9.9	8.4	8.0	13.0	14.4
B.	M.	28	6.3	4.9	5.4	3.0	3.0	3.8	5.4	8.4	6.5	8.4	8.7
G.	F.	23	9.0	6.8	8.0	5.0	6.5	6.2	6.0	5.6	7.7	9.0	9.7
B.	M.	23	10.8	6.0	9.8	7.1	8.3	8.2	8.0	8.5	8.2	10.8	11.0
K.	M.	19	8.8	7.0	10.0	7.0	7.8	8.4	6.7	9.4	9.5	10.0	10.5
J.	M.	36	9.2	6.1	8.3	4.5	7.2	7.9	5.8	7.1	6.8	9.2	10.0
K.	M.	26	10.8	9.4	7.9	7.9	8.6	8.7	7.7	8.4	7.4	10.8	11.1
M.	M.	31	9.3	7.1	10.8	5.9	7.4	6.7	8.0	8.2	9.8	10.8	12.0
Total			261.3	201.0	255.4	178.5	206.9	208.8	189.8	210.7	205.4	276.9	282.6
Average			10.44	8.05	10.20	7.15	8.28	8.36	7.60	8.44	8.22	11.08	11.31
Range			(6.3-12.7)	(4.9-11.8)	(5.4-14.0)	(3.0-12.7)	(4.4-11.7)	(3.8-12.0)	(3.8-11.0)	(5.3-13.4)	(5.5-12.5)	(9.0-14.0)	(8.7-14.7)

*Amplitude of evoked potential is measured from the base line to the peak of the negative deflection.(Fig.2)

***Max.Amp.Pot. is the amplitude of the highest action potential recorded from nine standard positions.

TABLE III

*Amplitude of evoked potential recorded from nine standard positions on Thenar muscle following stimulation of the (R) Median Nerve

25 Healthy Subjects

Subject	Sex	Age	Position of Recording Electrode 1	2	3	4	5	6	7	8	9	***Max.Amp.Pot. Elbow	Wrist
M.	F.	19	15.5	5.2	11.0	2.7	8.4	8.1	5.4	8.2	9.1	15.5	12.6
P.	F.	36	10.2	10.1	3.3	8.8	6.7	2.0	8.7	7.6	4.7	10.2	12.0
L.	M.	44	9.2	8.0	3.7	5.0	4.4	3.4	4.8	4.7	3.0	9.2	6.0
C.	M.	38	10.4	6.6	3.3	4.2	2.6	9.0	9.4	5.4	5.3	10.4	9.6
Z.	M.	48	11.5	5.0	12.8	6.8	7.2	8.4	8.5	8.8	7.0	12.8	10.7
C.	F.	22	12.0	8.1	6.4	6.3	2.3	5.8	8.0	8.8	5.4	12.0	12.0
M.	F.	18	13.0	5.4	12.2	2.2	7.6	4.4	6.3	6.3	5.3	13.0	10.8
B.	M.	30	13.8	10.4	12.4	4.2	10.9	9.5	10.6	9.8	9.9	13.8	13.2
R.	F.	24	11.8	4.0	10.4	4.4	4.3	5.2	5.2	5.6	9.2	11.8	8.8
D.	F.	20	12.8	7.8	8.0	6.8	8.8	8.5	7.8	9.6	10.0	12.8	12.0
G.	F.	20	12.8	10.7	12.7	5.2	10.5	11.3	9.1	9.8	6.8	12.8	12.9
A.	F.	23	6.5	2.8	8.6	2.1	6.1	6.8	3.0	2.8	3.0	8.6	7.2
S.	M.	24	11.5	4.4	9.1	4.3	4.0	3.5	3.8	7.4	6.8	11.5	10.3
S.	F.	21	11.0	4.6	4.4	11.5	2.9	6.2	6.0	6.9	6.8	11.0	11.7
E.	F.	20	11.5	5.0	9.1	2.3	5.3	5.7	5.0	4.6	4.0	11.5	6.9
P.	F.	19	14.5	4.4	14.5	5.8	7.2	6.5	7.5	4.8	2.0	14.5	14.1
E.	F.	20	14.0	7.1	13.3	5.8	10.4	10.5	2.0	8.2	4.4	14.0	11.3
L.	F.	19	11.9	7.1	7.8	4.1	9.4	5.3	6.7	5.3	5.8	11.9	10.5
B.	M.	28	7.0	3.8	8.3	2.4	5.0	4.0	3.8	3.8	5.0	7.0	8.1
G.	F.	23	8.5	5.8	10.5	2.3	5.1	5.3	3.9	3.8	3.8	10.5	10.0
B.	M.	23	10.3	5.6	11.1	4.3	7.4	7.9	3.0	5.0	4.4	11.1	12.4
K.	M.	19	10.5	7.8	14.6	6.0	6.7	9.1	6.3	5.8	5.0	14.6	14.5
J.	M.	36	9.9	5.2	3.7	7.4	5.8	4.5	3.8	3.1	4.0	9.9	8.0
K.	M.	26	12.8	6.7	8.2	11.7	4.0	10.0	8.7	5.1	7.3	12.8	10.0
M.	M.	31	8.8	3.1	9.9	4.4	6.0	5.8	4.0	5.2	6.8	9.9	9.6
	Total		281.7	154.7	229.3	131.0	159.0	166.7	151.3	156.4	144.8	293.1	265.2
	Average		11.26	6.19	9.17	5.24	6.33	6.66	6.05	6.25	5.79	11.70	10.60
	Range		(6.5-15.5)	(3.1-7.0)	(3.3-14.6)	(2.1-11.7)	(2.3-10.9)	(2.0-11.3)	(2.0-10.6)	(2.8-9.8)	(2.0-10.0)	(7.0-15.5)	(6.0-14.5)

*Amplitude of evoked potential is measured from the base line to the peak of the negative deflection.(Fig.2)

***Max.Amp.Pot. is the amplitude of the highest action potential recorded from nine standard positions.

TABLE IV

*Amplitude of evoked potential recorded from nine standard positions

on Thenar muscle following stimulation of the (L) Median Nerve

Subject	Sex	Age	Position of Recording Electrode 1	2	3	4	5	6	7	8	9	***Max.Amp.Pot. Elbow	Wrist
M.	F.	19	16.8	3.5	8.6	4.9	5.0	6.8	4.5	5.4	7.8	16.8	12.3
P.	F.	36	11.8	9.7	5.8	6.0	4.5	1.9	11.2	12.1	9.8	12.1	12.3
L.	M.	44	10.1	10.3	9.5	5.0	5.1	5.9	5.2	6.5	6.6	10.3	8.5
C.	M.	38	14.2	13.5	10.1	4.1	2.8	3.8	9.6	11.0	9.4	14.2	11.0
Z.	M.	48	12.0	6.8	12.0	3.2	8.3	8.7	10.4	10.7	10.8	12.0	11.8
C.	F.	22	11.4	7.8	7.8	7.9	9.8	8.4	6.4	6.0	4.0	11.4	8.8
M.	F.	18	11.9	6.6	10.0	6.0	6.5	2.4	6.3	8.0	7.4	11.9	10.0
B.	M.	30	13.5	8.0	11.0	4.0	5.0	7.2	8.3	9.3	10.8	13.5	10.2
R.	F.	24	10.1	5.0	12.0	2.7	6.8	7.2	3.9	6.2	8.1	12.0	8.2
D.	F.	20	12.1	2.8	4.2	2.8	5.5	5.9	7.4	9.4	9.5	12.1	9.6
G.	F.	20	12.9	10.8	12.9	7.8	7.5	9.6	7.1	7.1	2.7	12.9	12.2
A.	F.	23	7.1	4.9	10.9	4.1	6.4	6.4	8.0	4.8	4.8	10.9	9.8
S.	M.	24	8.0	4.9	12.0	3.5	5.0	5.2	3.5	4.0	5.5	12.0	12.0
S.	F.	21	11.0	7.4	10.4	2.1	3.8	3.7	8.1	8.4	8.1	11.0	11.8
E.	F.	20	9.0	4.9	8.2	2.3	7.8	8.0	3.9	4.3	3.1	9.0	7.5
P.	F.	19	10.4	7.1	12.7	2.5	5.0	5.8	4.4	4.7	3.8	12.7	12.3
E.	F.	20	12.8	6.8	13.0	4.0	4.9	5.0	9.9	7.9	8.2	13.0	12.9
L.	F.	19	12.8	5.4	9.7	4.9	7.3	6.0	3.1	3.0	3.7	12.8	13.4
B.	M.	28	5.8	2.0	5.0	1.6	1.5	2.2	1.3	1.4	3.5	5.8	5.7
G.	F.	23	8.0	3.8	8.8	3.4	5.6	4.8	3.8	4.7	6.7	8.8	8.7
B.	M.	23	10.2	8.1	12.2	6.4	7.1	9.4	5.1	7.4	4.2	12.2	11.5
K.	M.	19	13.5	10.8	15.1	8.7	8.4	8.5	10.0	8.7	8.1	15.1	14.0
J.	M.	36	7.1	3.8	8.0	2.6	4.4	7.1	4.2	3.9	4.5	8.0	8.5
K.	M.	26	12.4	6.2	11.4	2.7	8.2	9.0	5.1	6.0	6.8	12.4	10.0
M.	M.	31	10.4	5.2	12.0	3.8	6.2	7.4	4.1	5.2	7.3	12.0	9.7
Total			275.3	166.1	253.3	107.0	148.4	156.3	154.8	166.1	165.2	294.9	262.7
Average			11.05	6.65	10.10	4.28	5.94	6.25	6.20	6.65	6.60	11.70	10.50
Range			(5.8-16.8)	(2.0-13.5)	(5.0-15.1)	(2.1-8.7)	(2.8-9.8)	(1.9-9.6)	(1.3-11.2)	(1.4-12.1)	(2.7-10.8)	(5.8-16.8)	(5.7-14.0)

*Amplitude of evoked potential is measured from the base line to the peak of the negative deflection. (Fig.2)

***Max.Amp.Pot. is the amplitude of the highest action potential recorded from nine standard positions.

TABLE V-A

Summary of Averages of Measurements of *Amplitude (mv) of evoked Potentials related to nine standard recording positions on Hypothenar and Thenar Muscles following stimulation** of Ulnar and Median Nerves

25 Healthy Subjects

No. of Subjects	Muscle - Nerve	Side		*AMPLITUDE (mv) related to Position of Recording Electrode 1	2	3	4	5	6	7	8	9	***Max.Amp.Pot. Elbow	Wrist
25	Hypothenar Ulnar	(R)	Av.	10.36	7.98	9.86	7.19	7.97	8.18	7.26	7.90	8.31	10.95	11.06
			Range	(7.0-13.7)	(5.6-10.4)	(6.6-13.8)	(4.2-10.0)	(4.7-11.8)	(4.7-12.1)	(4.2-11.6)	(4.2-13.1)	(4.1-13.8)	(7.9-13.7)	(7.8-14.4)
			S.D.	1.79		1.64						2.18	1.61	1.67
25		(L)	Av.	10.44	8.05	10.20	7.15	8.28	8.36	7.60	8.44	8.22	11.08	11.31
			Range	(6.3-12.7)	(4.9-11.8)	(5.4-14.0)	(3.0-12.7)	(4.4-11.7)	(3.8-12.0)	(3.8-11.0)	(5.3-13.4)	(5.5-12.5)	(9.0-14.0)	(8.7-14.7)
			S.D.	1.57		2.05						1.89	1.59	2.01
25	Thenar Median	(R)	Av.	11.26	6.19	9.17	5.24	6.33	6.66	6.05	6.25	5.79	11.70	10.60
			Range	(6.5-15.5)	(3.1-7.0)	(3.3-14.6)	(2.1-11.7)	(2.3-10.9)	(2.0-11.3)	(2.0-10.6)	(2.8-9.8)	(2.0-10.0)	(7.0-15.5)	(6.0-14.5)
			S.D.	2.21		3.50						2.16	2.01	2.23
25		(L)	Av.	11.05	6.65	10.10	4.28	5.94	6.25	6.20	6.65	6.60	11.70	10.50
			Range	(5.8-16.8)	(2.0-13.5)	(5.0-15.1)	(2.1-8.7)	(2.8-9.8)	(1.9-9.6)	(1.3-11.2)	(1.4-12.1)	(2.7-10.8)	(5.8-16.8)	(5.7-14.0)
			S.D.	2.59		2.63						2.48	2.24	2.04

*Amplitude of evoked potential is measured from the base line to the peak of the negative deflection.

**Stimulation is always supramaximal and at the elbow except where recording the highest action potential (Max. Amp. Pot.) following stimulation at the wrist.

***Max. Amp. Pot. is the amplitude of the highest action potential recorded from nine standard positions.

TABLE V-B

Frequency (%) of Recording highest action potentials (*Max. Amp. Pot.) from any one standard position on Hypothenar and Thenar Muscles following stimulation** of Ulnar and Median Nerves

No. Of Subjects	Muscle - Nerve	Side	Position of Recording Electrodes								
			1	2	3	4	5	6	7	8	9
25	Hypothenar Ulnar	(R)	59.5	0	29.6	0	0	0	0	0	11.1
		(L)	46.2	0	42.3	0	0	0	0	7.7	3.8
25	Thenar Median	(R)	73.1	0	26.9	0	0	0	0	0	0
		(L)	48.2	3.7	44.4	0	0	0	0	3.7	0

*Max. Amp. Pot. is the amplitude of the highest action potential recorded from nine standard positions.

**Stimulation is always supramaximal and at the elbow except where recording the highest action potential (Max. Amp. Pot.) following stimulation at the wrist.

TABLE V-C

Difference between amplitude of evoked potential from position one and the highest action potential recorded from the Hypothenar and Thenar Muscles following stimulation of the Ulnar and Median Nerves

25 Healthy Subjects

Side Nerve	Amp.P. 1	Max.Amp.Pot.	Difference	%Increase
(R) ULNAR				
	10.3	11.2	0.9	8.0
	9.0	9.7	0.7	7.8
	7.8	13.8	6.0	77.0
In 16 out of 25	9.6	9.8	0.2	2.8
Amp.P. 1 =	10.2	11.0	0.8	7.8
Max.Amp.Pot.	10.2	12.0	1.8	17.6
	13.7	13.8	0.1	0.7
	8.1	9.6	1.5	18.5
	7.0	9.2	2.2	31.4
(L) ULNAR				
	11.7	12.7	1.0	8.6
	10.1	10.3	0.2	2.0
	12.4	14.0	1.6	12.9
	8.8	10.5	1.7	19.4
	11.6	14.0	2.4	20.6
In 12 out of 25	9.6	10.4	0.8	8.3
Amp.P. 1 =	8.8	9.2	0.4	4.5
Max.Amp.Pot.	12.4	13.4	1.0	8.1
	8.8	9.0	0.2	2.3
	11.5	13.0	1.5	1.3
	6.3	8.4	2.1	33.3
	8.8	10.0	1.2	13.6
	9.3	10.8	1.5	16.2
Total	216.0	245.8	29.8	332.7
Average of 50			0.59	6.7
Range	(6.3-13.7)	(8.4-14.0)	(0.0-2.2)	(0 - 77.0)

P. = R. < .1
L. < .1

Side Nerve	Amp.P. 1	Max.Amp.Pot.	Difference	%Increase
(R) Median				
	11.5	12.8	1.3	11.3
	6.5	8.6	2.1	32.3
	8.5	10.5	2.0	23.5
20 Individuals:	10.5	14.6	4.1	39.0
Amp.P. 1 =	8.8	9.9	1.1	12.5
Max.Amp.Pot.				
(L) Median				
	11.8	12.1	0.3	2.5
	10.1	10.3	0.2	2.0
	10.1	12.0	1.9	18.8
	7.1	10.9	3.8	53.5
	8.0	12.0	4.0	50.0
In 13 out of 25	10.4	12.7	2.3	22.1
Amp.P. 1 =	12.8	13.0	0.2	1.6
Max.Amp.Pot.	8.0	8.8	0.8	10.0
	10.2	12.2	2.0	19.6
	13.5	15.1	1.6	11.8
	7.1	8.0	0.9	12.7
	10.4	12.0	1.6	15.4
Total	165.3	195.5	30.2	338.6
Average of 50				6.8
Range	(6.5-13.5)	(8.0-13.0)	(0.0-4.1)	(0 - 53.5)

P. = R. < .2
L. < .1

TABLE VI

Conduction times wrist to thenar (adductor pollicis) and wrist to hypothenar and amplitudes of action potentials from thenar* following stimulation** of ulnar nerve

25 Healthy Subjects

Subject	Sex	Age	RIGHT ULNAR Conduction Time (msec) Wrist to Thenar	Hypothenar		Amplitude (mv) stim. at Wrist	Elbow	LEFT ULNAR Conduction Time (msec) Wrist to Thenar	Hypothenar		Amplitude (mv) stim. at Wrist	Elbow
M.	F.	19	2.5	2.0		5.3	6.0	2.7	2.3		6.3	6.0
P.	F.	36	3.1	2.3		7.5	7.4	2.9	2.1		3.4	3.0
L.	M.	44	3.2	2.3		3.4	2.8	3.1	2.3		1.3	1.2
C.	M.	38	2.8	2.0		6.4	6.2	3.5	2.7		4.1	3.4
Z.	M.	48	3.1	2.6		3.7	3.5	3.5	2.7		3.8	2.0
C.	F.	22	3.0	2.5		2.8	3.4	2.7	2.3		3.0	3.0
M.	F.	18	2.6	2.1		6.4	6.0	3.6	2.9		6.7	6.8
B.	M.	30	2.7	2.1		4.8	4.0	2.7	2.1		4.0	3.8
R.	F.	24	2.5	2.0		8.9	7.8	2.6	2.1		8.4	7.0
D.	F.	20	3.2	2.5		5.8	5.0	2.8	2.1		4.8	4.1
G.	F.	20	2.6	2.2		4.8	4.1	2.2	1.8		3.9	3.7
A.	F.	23	2.8	2.3	Mean	7.4	6.0	2.9	2.3	Mean	6.4	7.4
S.	M.	24	2.5	2.0	Difference	8.0	7.6	2.6	2.1	Difference	10.1	8.6
S.	F.	21	2.8	2.3	= 0.5	7.1	3.9	2.8	2.1	= 0.6	2.9	1.9
E.	F.	20	3.1	2.3		4.0	4.0	3.0	2.3		6.1	5.4
P.	F.	19	2.5	2.0	S.D. = ± .1	3.0	3.4	2.3	1.9	S.D. = ± .1	6.7	5.2
E.	F.	20	2.8	2.1		3.8	2.5	2.6	2.1		3.6	2.5
L.	F.	19	2.9	2.5	P. = $<$ .05	6.3	5.4	2.7	2.3	P. = $<$ .05	6.9	5.9
B.	M.	28	2.8	2.1		2.5	4.4	2.8	2.5		3.1	5.2
G.	F.	23	2.9	2.3		6.0	5.3	3.2	2.5		4.9	4.3
B.	M.	23	2.9	2.3		8.3	6.2	2.6	2.1		8.2	7.8
K.	M.	19	3.5	3.0		4.4	4.2	3.6	3.0		3.7	3.5
J.	M.	36	2.7	3.2		9.0	7.8	2.5	2.0		8.6	7.3
K.	M.	26	3.3	2.9		3.9	3.5	2.4	2.1		2.5	3.0
M.	M.	31	2.9	2.3		4.8	4.2	3.0	2.5		3.9	3.3
Total			71.7	58.2		138.3	124.6	71.3	57.2		127.3	115.3
Average			2.83	2.33		5.54	5.00	2.81	2.21		5.09	4.52
Range			(2.5-3.5)	(2.0-3.2)		(2.5-9.0)	(2.5-7.8)	(2.2-3.6)	(1.8-3.0)		(1.3-10.1)	(1.2-8.6)

*Amplitudes of action potentials and conduction times are measured from and to recording electrode on position one on thenar muscles.

**Point of stimulation remained the same, whether recording from hypothenar or thenar muscle.

TABLE VII-A

Duration of evoked potential recorded from nine standard positions

on the Hypothenar muscle following stimulation of the (R) Ulnar Nerve

25 Healthy Subjects

*SPIKE DURATION (msecs)

Subject	Sex	Age	Position of Recording Electrode 1	2	3	4	5	6	7	8	9	Wrist Stimulation Pos. Max.
M.	F.	19	5.1	5.2	5.1	5.3	6.1	5.8	7.8	6.0	5.2	5.1
P.	F.	36	4.9	5.0	5.0	5.2	5.2	5.4	5.3	5.6	5.5	4.5
L.	M.	44	5.5	5.5	5.5	6.2	5.6	5.3	7.2	7.1	5.9	5.2
C.	M.	38	5.0	4.9	5.8	6.0	6.0	6.0	6.0	5.0	5.4	6.6
Z.	M.	48	6.7	6.7	5.8	7.0	7.2	7.0	7.0	7.4	7.0	6.4
C.	F.	22	7.0	7.0	7.0	7.2	7.4	7.0	7.2	7.0	7.2	7.6
M.	F.	18	7.0	6.3	6.0	6.9	5.0	5.1	5.0	6.1	7.6	7.0
B.	M.	30	6.1	5.6	5.6	6.2	6.1	6.2	6.0	6.0	6.0	5.8
R.	F.	24	6.2	7.1	7.0	8.0	8.0	6.1	7.1	6.7	8.0	6.0
D.	F.	20	7.0	7.0	6.4	6.0	6.2	6.2	7.7	7.8	6.2	5.9
G.	F.	20	5.8	5.1	6.0	5.0	5.1	5.1	6.1	6.0	6.5	5.9
A.	F.	23	7.2	6.2	6.1	6.3	6.4	6.4	6.1	6.1	6.0	5.2
S.	M.	24	5.3	4.6	4.7	6.2	6.1	6.1	4.6	4.6	4.0	4.8
S.	F.	21	6.1	6.2	6.0	8.0	8.1	8.1	6.0	5.8	5.0	5.3
E.	F.	20	6.5	6.0	6.0	5.3	5.1	5.1	5.4	6.0	5.9	5.4
P.	F.	19	5.2	4.6	4.7	5.0	5.0	5.0	4.6	4.6	4.2	4.5
E.	F.	20	6.2	5.0	5.0	6.5	7.2	7.0	6.0	5.9	8.2	5.9
L.	F.	19	6.5	5.8	6.5	6.8	7.0	7.0	6.1	6.2	6.1	6.3
B.	M.	28	4.7	5.0	5.0	5.0	5.0	5.0	4.6	5.0	4.8	4.9
G.	F.	23	7.2	6.4	6.2	9.0	8.6	8.8	5.7	8.0	8.8	5.7
B.	M.	23	6.3	6.2	5.1	6.5	6.0	6.0	5.8	5.2	5.6	5.3
K.	M.	19	6.2	6.1	5.3	6.3	6.9	6.9	5.8	5.8	6.0	5.7
J.	M.	36	5.2	5.0	5.0	5.1	5.5	5.5	5.2	5.5	7.2	5.0
K.	M.	26	5.5	5.5	5.5	5.0	5.9	5.9	5.5	5.0	4.6	5.1
M.	M.	31	5.4	5.3	5.6	6.2	7.3	7.3	5.3	5.6	5.5	5.0
Total			149.8	143.3	141.9	156.2	158.0	155.3	149.1	150.0	152.4	140.1
Average			5.98	5.74	5.66	6.25	6.35	6.22	5.97	6.00	6.10	5.61
Range			(7.2-4.7)	(7.1-4.6)	(7.0-4.7)	(9.0-5.0)	(8.1-5.0)	(8.8-5.0)	(7.8-4.6)	(8.0-4.6)	(8.8-4.2)	(7.6-4.5)

*Spike duration is the time (msec) from the beginning of the potential to the point where the descending limb of the negative deflection intercepts the base line. (Fig. 2)

TABLE VII-B

Duration of evoked potential recorded from nine standard positions on the Hypothenar muscle following stimulation of the (L) Ulnar Nerve

25 Healthy Subjects

*SPIKE DURATION (msecs)

Subject	Sex	Age	Position of Recording Electrode 1	2	3	4	5	6	7	8	9	Wrist Stimulation Pos.Max.
M.	F.	19	6.0	5.2	5.0	5.1	6.0	6.0	6.0	7.2	5.2	5.1
P.	F.	36	5.0	5.9	5.1	5.8	5.9	6.0	6.0	5.9	5.4	5.0
L.	M.	44	5.9	5.5	5.6	6.0	6.0	6.0	6.0	6.1	5.0	5.3
C.	M.	38	6.1	5.7	5.6	6.5	6.6	6.2	5.6	5.4	7.1	4.0
Z.	M.	48	6.0	6.3	5.3	7.5	7.0	7.5	7.0	7.0	7.0	6.0
C.	F.	22	6.0	6.5	6.7	6.9	7.0	7.2	6.0	7.2	7.0	6.0
M.	F.	18	8.8	6.0	6.2	6.5	6.5	6.5	6.3	6.0	6.5	4.8
B.	M.	30	5.6	6.0	6.0	6.2	6.0	6.0	6.0	6.0	6.1	5.4
R.	F.	24	5.9	4.9	5.4	5.4	6.0	5.8	5.6	5.8	7.0	6.0
D.	F.	20	7.0	7.7	7.0	9.0	8.3	8.0	7.0	7.4	7.2	6.9
G.	F.	20	5.4	5.4	5.2	4.7	5.4	5.2	5.1	4.9	4.8	5.0
A.	F.	23	7.4	8.5	7.0	9.8	9.0	9.2	6.9	6.7	6.7	8.0
S.	M.	24	5.2	5.0	4.7	5.2	5.1	5.1	5.0	4.3	4.5	6.1
S.	F.	21	7.0	6.4	6.0	6.4	8.5	7.4	6.0	6.0	8.0	6.0
E.	F.	20	6.1	5.4	5.8	6.2	6.2	6.1	5.8	6.0	5.1	5.2
P.	F.	19	5.2	4.2	5.0	4.2	4.0	4.1	4.0	4.0	4.5	4.0
E.	F.	20	6.0	6.2	5.4	6.0	6.3	6.2	5.3	5.6	5.3	5.6
L.	F.	19	7.0	5.0	5.0	4.7	7.1	7.2	5.6	7.1	7.0	5.1
B.	M.	28	7.0	5.8	5.1	6.0	6.0	5.2	4.5	4.5	4.5	4.3
G.	F.	23	7.8	7.0	5.5	7.8	8.5	8.5	7.5	8.6	8.5	8.1
B.	M.	23	6.6	6.3	6.8	7.0	7.0	7.0	6.1	6.0	6.1	5.9
A.	M.	19	5.5	5.5	5.3	5.9	6.0	6.2	5.8	4.9	5.2	5.0
J.	M.	36	5.1	5.6	5.3	7.3	6.0	5.0	5.0	5.1	5.1	5.2
K.	M.	26	5.5	5.5	5.5	5.9	6.0	6.2	5.5	5.1	5.2	4.8
M.	M.	31	6.4	6.4	5.8	6.8	7.0	6.8	5.5	5.6	6.0	4.4
	Total		155.5	147.9	141.3	158.8	163.4	160.6	145.1	148.4	150.0	137.2
	Average		6.22	5.89	5.66	6.35	6.64	6.61	5.82	5.94	6.00	5.58
	Range		(7.8-5.0)	(7.7-4.2)	(7.0-4.7)	(9.0-4.2)	(9.0-4.0)	(9.2-4.1)	(7.5-4.0)	(8.6-4.0)	(8.5-4.0)	(8.1-4.0)

*Spike duration is the time (msec) from the beginning of the potential to the point where the descending limb of the negative deflection intercepts the base line. (Fig.2)

TABLE VIII-A

Duration of evoked potential recorded from nine standard positions

on the Hypothenar muscle following stimulation of the (R) Ulnar Nerve

25 Healthy Subjects

*TOTAL DURATION (msecs)

Subject	Sex	Age	Position of Recording Electrode 1	2	3	4	5	6	7	8	9	Wrist Stimulation Pos.Max.
M.	F.	19	8.2	8.3	7.9	8.2	8.5	8.9	8.0	8.2	7.4	7.2
P.	F.	36	8.0	8.0	7.5	7.5	7.6	7.7	7.7	7.8	7.8	7.9
L.	M.	44	8.2	8.3	8.4	8.2	7.6	7.8	9.1	9.2	8.7	7.2
C.	M.	38	8.2	8.1	8.6	8.0	9.0	9.0	8.9	9.0	8.6	8.0
Z.	M.	48	9.0	9.0	8.5	9.3	9.0	9.0	9.5	9.9	9.6	8.5
C.	F.	22	9.0	9.0	9.4	9.3	9.5	9.5	9.2	10.0	10.0	9.0
M.	F.	18	9.2	9.3	9.2	10.2	9.2	9.2	10.5	11.0	10.6	10.0
B.	M.	30	7.6	7.6	7.4	7.5	7.4	7.4	7.4	7.5	7.4	10.0
R.	F.	24	10.0	10.2	10.0	10.0	10.0	10.0	10.0	9.6	10.0	7.3
D.	F.	20	10.5	10.4	9.5	10.0	10.0	10.0	10.6	10.0	10.5	10.0
G.	F.	20	8.4	8.6	8.2	8.1	8.3	8.3	8.5	8.2	8.5	9.7
A.	F.	23	10.0	10.2	10.0	10.3	10.8	10.8	10.1	10.1	10.0	8.4
S.	M.	24	7.2	8.5	7.3	7.7	7.2	7.2	7.2	6.6	7.4	8.4
S.	F.	21	10.2	10.1	10.0	10.0	10.1	10.1	10.2	9.8	10.1	7.1
E.	F.	20	9.0	10.3	9.5	10.0	10.0	10.0	9.8	9.2	9.6	10.1
P.	F.	19	6.7	6.7	6.5	6.2	6.5	6.5	6.5	6.5	6.5	8.5
E.	F.	20	9.1	8.9	9.0	8.6	9.1	9.1	10.0	9.6	9.3	6.5
L.	F.	19	9.3	8.8	8.2	8.7	8.9	8.9	8.5	8.4	8.1	9.0
B.	M.	28	7.2	7.0	7.0	7.0	7.0	7.0	6.8	6.8	7.0	8.2
G.	F.	23	11.4	11.4	11.3	11.4	11.6	11.6	12.1	11.7	11.0	6.1
B.	M.	23	8.2	8.3	8.0	8.0	8.3	8.3	7.6	7.6	7.2	11.6
K.	M.	19	8.1	8.2	8.0	9.4	8.5	8.5	8.0	8.0	8.0	7.8
J.	M.	36	8.2	8.4	8.3	8.4	8.2	8.2	8.2	8.2	8.9	8.4
K.	M.	26	7.1	7.0	7.0	7.5	7.8	7.8	6.5	9.0	5.5	8.6
M.	M.	31	7.3	7.8	8.1	8.2	8.5	8.5	9.1	9.2	8.6	8.0
	Total		215.3	218.4	212.8	217.7	218.6	219.3	220.0	221.1	216.3	204.3
	Average		8.60	8.74	8.54	8.69	8.76	8.79	8.80	8.84	8.67	8.16
	Range		(11.4-7.1)	(11.4-6.7)	(11.3-6.5)	(11.4-6.2)	(11.6-6.5)	(11.6-6.5)	(12.1-6.5)	(11.7-6.5)	(11.0-5.5)	(11.6-7.1)

*Total duration is the time (msec) from the beginning of the potential to the point of the positive deflection. (Fig.2)

TABLE VIII-B

Duration of evoked potential recorded from nine standard positions

on the Hypothenar muscle following stimulation of the (L) Ulnar Nerve

25 Healthy Subjects

*TOTAL DURATION (msecs)

Subject	Sex	Age	Position of Recording Electrode 1	2	3	4	5	6	7	8	9	Wrist Stimulation Pos.Max.
M.	F.	19	9.5	9.9	9.0	9.0	9.5	9.8	9.2	9.5	9.5	9.0
P.	F.	36	8.0	8.1	8.1	8.1	8.0	8.0	8.4	8.4	8.4	8.2
L.	M.	44	9.0	8.6	8.7	8.6	8.4	9.0	9.3	9.2	8.6	8.1
C.	M.	38	9.2	9.3	9.5	9.9	10.0	9.0	10.4	10.0	9.6	9.8
Z.	M.	48	9.0	9.0	8.5	9.5	9.4	9.3	9.7	9.3	9.1	9.0
C.	F.	22	8.6	9.0	9.0	9.2	9.1	9.3	8.5	9.1	9.0	8.5
M.	F.	18	11.5	11.5	10.0	10.5	10.3	11.0	11.5	11.0	11.5	10.0
B.	M.	30	8.0	8.0	8.0	8.2	8.1	8.0	8.5	8.2	8.3	7.3
R.	F.	24	9.0	9.2	9.0	9.1	9.2	9.1	9.1	9.0	9.1	9.0
D.	F.	20	8.9	9.7	9.2	9.1	9.5	9.3	9.5	9.8	9.9	9.0
G.	F.	20	7.2	7.4	7.2	6.8	6.4	7.1	6.3	6.0	6.0	6.4
A.	F.	23	11.0	11.5	11.5	11.4	11.0	11.5	11.0	11.0	10.5	11.0
S.	M.	24	6.7	7.1	7.0	7.2	7.1	7.1	7.1	6.6	7.0	7.0
S.	F.	21	11.0	11.1	10.6	10.5	10.6	10.7	10.6	10.6	10.2	10.1
E.	F.	20	8.9	9.1	9.1	9.0	9.2	9.1	9.5	9.5	8.6	9.2
P.	F.	19	7.0	7.0	6.2	7.0	6.2	6.3	6.3	6.5	6.8	6.4
E.	F.	20	8.4	8.3	8.2	8.0	8.1	8.1	8.0	8.2	8.4	8.1
L.	F.	19	9.0	9.0	9.0	8.9	9.0	9.0	9.0	9.2	9.0	8.9
B.	M.	28	7.8	6.2	8.2	8.0	8.0	8.4	6.2	6.5	7.4	7.0
G.	F.	23	12.0	12.0	12.0	11.4	12.0	11.9	12.0	12.0	11.8	11.8
B.	M.	23	8.2	8.2	8.2	8.3	8.3	8.3	8.3	8.2	8.1	7.9
K.	M.	19	8.0	8.1	8.0	8.4	8.5	8.1	8.1	8.0	8.2	8.0
J.	M.	36	8.2	8.6	8.4	9.0	8.2	8.3	8.4	8.2	8.1	8.1
K.	M.	26	8.0	8.3	8.1	8.0	8.0	8.2	8.1	7.4	7.1	7.0
M.	M.	31	8.5	9.1	8.3	8.8	9.0	7.5	9.0	9.1	8.4	8.0
Total			220.6	223.3	219.0	221.9	221.1	221.4	222.0	220.5	218.6	212.8
Average			8.84	8.91	8.75	8.85	8.84	8.85	8.89	8.80	8.75	8.44
Range			(12.0-7.0)	(12.0-62.)	(12.0-6.2)	(11.4-7.0)	(12.0-6.2)	(11.9-6.3)	(12.0-6.2)	(12.0-6.5)	(11.8-6.0)	(11.8-6.4)

*Total duration is the time (msec) from the beginning of the potential to the peak of the positive deflection. (Fig.2)

TABLE IX-A

Duration of evoked potential recorded from nine standard positions on the Thenar muscle following stimulation of the (R) Median Nerve

25 Healthy Subjects

*SPIKE DURATION (msecs)

Subject	Sex	Age	Position of Recording Electrode									Wrist Stimulation
			1	2	3	4	5	6	7	8	9	Pos.Max.
M.	F.	19	5.0	5.1	5.0	7.0	6.0	5.0	6.0	5.4	5.2	5.0
P.	F.	36	4.9	4.8	4.9	5.0	4.8	4.8	5.1	5.0	4.6	4.5
L.	M.	44	5.2	5.2	5.1	5.0	5.2	5.4	5.4	5.5	5.5	4.6
C.	M.	38	6.7	5.1	4.0	5.1	4.0	6.1	8.0	5.4	5.3	4.9
Z.	M.	48	6.0	6.1	5.7	5.9	6.2	5.6	6.0	6.2	6.2	5.5
C.	F.	22	6.0	6.0	5.6	6.0	6.0	6.5	6.2	6.5	6.0	5.8
M.	F.	18	5.4	6.0	5.0	5.0	6.0	5.0	6.2	6.0	6.0	6.1
B.	M.	30	4.3	4.4	4.5	5.0	5.1	4.0	4.5	5.1	5.0	4.6
R.	F.	24	6.0	7.0	6.0	6.5	7.0	7.6	7.0	6.6	5.8	5.8
D.	F.	20	6.2	6.1	6.0	5.5	6.0	6.1	6.4	6.2	6.0	6.0
G.	F.	20	6.0	6.2	5.5	6.2	6.0	6.0	6.1	6.8	6.0	6.0
A.	F.	23	5.0	5.0	4.5	4.0	4.5	4.5	5.8	5.2	5.1	4.1
S.	M.	24	5.0	6.0	5.4	6.1	6.3	6.0	5.9	5.6	5.3	5.0
S.	F.	21	5.9	6.0	7.1	5.5	7.5	5.2	7.2	6.2	6.3	5.1
E.	F.	20	5.2	5.1	5.0	5.1	5.1	5.3	5.5	5.8	6.7	5.2
P.	F.	19	4.6	5.0	4.8	4.2	4.4	4.3	5.0	5.0	5.6	5.0
E.	F.	20	5.5	7.0	4.3	7.4	6.3	4.7	4.6	6.5	7.0	5.8
L.	F.	19	5.9	5.3	7.0	7.4	5.4	5.0	5.4	7.3	5.5	5.2
B.	M.	28	5.1	5.2	5.0	5.6	5.4	5.0	6.0	5.2	6.0	4.6
G.	F.	23	6.2	6.5	6.0	5.0	5.8	8.0	6.0	6.0	10.5	5.6
B.	M.	23	5.0	5.0	4.6	5.2	4.3	4.5	7.3	7.0	8.3	4.4
K.	M.	19	6.2	5.8	5.3	5.8	5.2	6.2	7.5	6.1	6.1	5.5
J.	M.	36	4.1	4.2	4.3	4.8	3.8	5.0	6.0	7.0	5.5	4.0
K.	M.	26	5.7	6.3	5.9	5.8	6.1	5.7	5.6	6.7	6.6	5.4
M.	M.	31	5.6	5.0	5.5	5.9	5.5	5.9	6.5	6.5	5.2	5.0
	Total		136.7	139.4	132.0	140.0	137.9	137.4	151.2	150.8	151.3	128.7
	Average		5.47	5.58	5.25	5.60	5.52	6.50	6.05	6.03	6.05	5.15
	Range		(6.7-4.1)	(7.0-4.2)	(7.1-4.0)	(7.4-4.0)	(7.5-3.8)	(8.0-4.0)	(8.0-4.5)	(7.3-5.0)	(10.5-4.6)	(6.1-4.0)

*Spike duration is the time (msecs) from the beginning of the potential to the point where the descending limb of the negative deflection intercepts the base line. (Fig.2)

TABLE IX-B

Duration of evoked potential recorded from nine standard positions on the Thenar muscle following stimulation of the (L) Median Nerve

25 Healthy Subjects

*SPIKE DURATION (msecs)

Subject	Sex	Age	Position of Recording Electrode 1	2	3	4	5	6	7	8	9	Wrist Stimulation Pos.Max.
M.	F.	19	5.0	5.1	5.8	5.7	6.0	5.8	6.0	6.1	6.0	5.1
P.	F.	36	5.2	5.2	5.0	5.2	5.1	5.0	5.0	5.0	5.1	5.1
L.	M.	44	4.5	4.5	4.6	4.1	4.2	4.2	4.1	4.5	5.0	4.5
C.	M.	38	5.4	5.4	5.8	5.4	7.5	7.3	7.0	6.9	6.3	6.0
Z.	M.	48	5.0	5.0	5.0	5.0	5.0	5.0	6.0	5.2	5.2	6.0
C.	F.	22	6.2	6.2	6.1	7.0	6.5	6.7	7.0	8.0	7.5	6.2
M.	F.	18	6.3	6.3	6.0	8.0	7.0	6.3	6.9	7.0	6.2	6.7
B.	M.	30	6.0	6.0	5.5	6.5	6.5	5.0	5.4	5.7	5.5	4.8
R.	F.	24	5.0	5.0	5.0	6.4	5.2	5.0	6.0	6.0	5.5	5.1
D.	F.	20	5.9	5.9	7.0	7.0	5.0	4.5	5.8	5.8	6.3	5.0
G.	F.	20	5.5	5.5	5.3	5.0	5.1	5.1	5.1	5.3	5.2	5.0
A.	F.	23	5.3	5.3	5.0	4.5	5.5	5.0	5.0	5.8	5.3	5.2
S.	M.	24	4.6	4.6	4.2	5.0	6.0	6.0	6.0	5.1	5.1	3.9
S.	F.	21	6.5	6.5	6.1	9.0	7.0	7.0	7.0	6.8	7.0	6.6
E.	F.	20	5.0	5.0	5.1	5.0	5.7	5.0	6.0	7.1	5.0	5.7
P.	F.	19	4.2	4.2	4.1	7.2	5.1	4.5	5.1	5.4	5.2	5.1
E.	F.	20	5.8	5.8	4.0	6.8	4.5	4.2	4.5	5.3	5.1	5.3
L.	F.	19	6.0	6.0	5.2	7.0	5.1	4.9	5.5	8.2	9.5	4.7
B.	M.	28	5.0	5.0	5.2	5.0	5.0	5.0	5.4	6.0	5.3	4.5
G.	F.	23	7.0	7.0	6.5	9.0	6.1	6.2	6.4	6.2	6.5	5.1
B.	M.	23	7.1	7.1	7.0	4.2	5.2	5.0	5.2	6.0	6.2	4.0
K.	M.	19	6.2	6.2	5.8	6.4	6.3	6.7	6.9	6.5	6.3	5.9
J.	M.	36	4.5	4.5	4.3	5.2	4.5	4.1	4.8	5.0	5.3	3.9
K.	M.	26	5.4	5.4	5.2	7.0	5.7	5.4	6.0	5.3	5.3	5.0
M.	M.	31	5.2	5.2	5.0	5.2	4.5	4.0	7.4	7.0	5.4	5.0
Total			137.8	137.9	133.8	151.8	139.3	132.9	145.5	151.2	146.3	129.4
Average			5.51	5.51	5.36	6.09	5.57	5.31	5.82	6.05	5.85	5.18
Range			(7.1-4.2)	(7.1-4.2)	(7.0-4.0)	(9.0-4.1)	(7.5-4.2)	(7.3-4.0)	(7.4-4.1)	(8.2-4.5)	(9.5-5.0)	(6.7-3.9)

*Spike duration is the time (msecs) from the beginning of the potential to the point where the descending limb of the negative deflection intercepts the base line. (Fig.2)

TABLE X-A

Duration of evoked potential recorded from nine standard positions on the Thenar muscle following stimulation of the (R) Median Nerve

25 Healthy Subjects

*TOTAL DURATION (msecs)

Subject	Sex	Age	Position of Recording Electrode 1	2	3	4	5	6	7	8	9	Wrist Stimulation Pos.Max.
M.	F.	19	7.2	7.3	6.4	8.2	7.6	8.0	7.5	7.5	7.0	7.0
P.	F.	36	7.9	7.9	7.9	7.9	8.0	8.0	7.0	7.9	7.8	6.9
L.	M.	44	8.0	8.1	8.1	8.2	8.4	8.5	7.0	7.1	7.5	7.5
C.	M.	38	11.5	11.5	10.1	10.5	11.0	11.7	11.6	10.0	10.4	11.3
Z.	M.	48	9.9	10.1	9.9	10.0	9.9	10.0	10.0	10.0	10.0	10.0
C.	F.	22	7.6	7.2	7.5	7.8	8.0	8.2	7.5	7.6	7.0	7.3
M.	F.	18	8.3	7.3	8.0	8.0	8.0	6.5	8.7	8.0	8.0	8.6
B.	M.	30	7.1	6.8	7.0	6.8	7.0	7.0	7.1	7.1	7.0	7.4
R.	F.	24	8.2	8.2	7.6	8.0	8.2	8.6	9.0	8.5	8.5	8.1
D.	F.	20	9.0	7.0	8.5	9.5	7.0	7.0	8.1	8.2	8.5	7.9
G.	F.	20	7.1	7.3	7.2	7.6	7.2	7.2	7.2	7.8	7.8	7.3
A.	F.	23	10.2	10.1	10.2	10.1	10.2	10.3	10.0	10.1	10.0	9.2
S.	M.	24	7.3	6.9	6.8	7.2	7.1	7.0	7.2	7.0	6.5	6.5
S.	F.	21	10.0	10.0	9.8	10.2	10.3	10.2	10.5	9.8	11.1	10.8
E.	F.	20	9.1	9.2	9.4	9.6	10.0	10.0	10.5	10.5	10.7	10.0
P.	F.	19	9.0	9.5	9.0	9.0	8.6	8.3	6.0	6.2	10.0	6.0
E.	F.	20	7.5	8.5	7.3	8.0	7.6	8.5	8.2	8.0	8.2	7.8
L.	F.	19	8.5	8.3	10.0	8.8	8.3	8.7	8.6	10.2	10.0	8.2
B.	M.	28	7.2	7.3	6.9	7.8	7.1	7.1	7.3	7.4	7.0	6.5
G.	F.	23	13.2	13.7	13.2	13.5	13.2	13.2	13.2	13.5	13.0	12.7
B.	M.	23	9.5	9.2	9.0	8.5	8.5	9.0	9.3	9.2	9.4	8.9
K.	M.	19	10.6	9.9	10.0	9.5	10.0	9.7	10.0	10.0	10.8	10.0
J.	M.	36	7.9	8.2	8.3	7.2	8.0	8.1	7.5	8.0	8.0	8.0
K.	M.	26	8.1	8.1	8.1	8.2	8.3	8.3	8.8	8.6	8.1	8.2
M.	M.	31	9.4	9.5	8.6	8.6	8.8	8.9	9.5	9.3	8.8	8.4
Total			219.3	217.1	214.8	218.7	216.3	218.0	217.3	217.5	211.1	210.5
Average			8.78	8.65	8.60	8.75	8.64	8.71	8.70	8.70	8.84	8.43
Range			(13.2-7.1)	(13.7-6.9)	(13.2-6.4)	(13.5-6.8)	(13.2-7.0)	(13.2-7.5)	(13.2-6.0)	(13.5-6.2)	(13.0-6.5)	(12.7-6.0)

*Total duration is the time (msecs) from the beginning of the potential to the peak of the positive deflection. (Fig.2)

TABLE X-B

Duration of evoked potential recorded from nine standard positions on the Thenar muscle following stimulation of the (L) Median Nerve

25 Healthy Subjects

*TOTAL DURATION (msecs)

Subject	Sex	Age	Position of Recording Electrode 1	2	3	4	5	6	7	8	9	Wrist Stimulation Pos.Max.
M.	F.	19	7.0	7.1	7.5	8.0	7.9	7.8	8.0	8.0	7.3	7.0
P.	F.	36	6.2	6.1	6.0	6.3	8.0	8.0	6.4	6.2	6.0	6.1
L.	M.	44	5.4	5.4	5.5	5.2	5.3	5.1	5.2	5.6	5.8	5.6
C.	M.	38	8.2	8.1	9.0	9.0	9.0	9.4	8.8	8.0	8.5	8.0
Z.	M.	48	10.0	10.0	10.0	10.0	10.3	10.0	7.5	7.9	7.9	7.2
C.	F.	22	8.0	10.8	11.0	10.8	11.0	10.3	11.0	11.0	11.0	11.0
M.	F.	18	9.0	8.3	8.3	9.8	9.0	9.0	9.3	9.0	8.5	9.0
B.	M.	30	8.0	7.8	7.6	8.0	7.8	8.0	7.4	7.0	7.5	7.0
R.	F.	24	8.0	8.2	7.1	8.2	8.0	8.6	8.0	8.0	8.0	8.0
D.	F.	20	8.1	9.2	9.0	10.0	9.2	7.0	7.0	7.8	7.5	8.4
G.	F.	20	6.6	6.7	6.5	6.9	6.3	6.2	6.2	6.3	6.1	6.0
A.	F.	23	10.5	11.3	11.3	11.2	11.5	11.5	12.0	11.8	11.3	11.2
S.	M.	24	6.9	6.9	6.0	6.0	7.0	7.0	7.0	6.5	7.0	6.0
S.	F.	21	8.0	8.0	7.5	10.9	10.5	10.6	8.0	7.9	8.0	8.0
E.	F.	20	10.5	10.2	9.2	10.1	9.0	9.0	10.2	10.2	9.0	10.0
P.	F.	19	7.0	7.1	5.4	8.5	8.2	8.3	8.0	8.1	8.0	6.3
E.	F.	20	7.3	7.0	5.6	11.3	8.0	8.0	7.8	7.3	7.5	7.5
L.	F.	19	9.2	9.0	8.9	9.0	9.0	9.3	9.1	9.0	11.5	9.0
B.	M.	28	8.2	9.0	8.0	8.0	7.6	7.4	8.8	8.5	6.5	8.2
G.	F.	23	12.2	12.5	12.3	12.0	12.0	12.0	13.0	13.0	13.5	12.2
B.	M.	23	8.8	9.0	9.0	8.8	8.7	8.2	8.8	8.0	8.2	8.1
K.	M.	19	7.5	7.5	7.5	10.3	10.2	8.2	7.9	10.2	10.1	7.9
J.	M.	36	7.1	7.3	7.0	7.5	7.4	7.2	7.5	6.9	6.4	7.0
K.	M.	26	8.0	8.3	8.1	8.3	8.2	8.1	8.5	8.0	8.0	7.8
M.	M.	31	8.2	8.3	8.0	8.5	8.5	8.1	8.8	8.0	8.0	8.0
Total			203.9	209.1	201.3	222.6	217.6	212.3	210.2	208.2	207.1	200.5
Average			8.15	8.36	8.05	8.90	8.70	8.50	8.40	8.33	8.28	8.00
Range			(12.2-5.4)	(12.5-6.4)	(13.3-5.5)	(12.0-5.2)	(12.0-5.3)	(12.0-5.1)	(13.0-5.2)	(13.0-5.6)	(13.5-5.8)	(12.2-5.6)

*Total duration is the time (msecs) from the beginning of the potential to the peak of the positive deflection. (Fig.2)

TABLE XI

Comparison of Conduction Velocity and Residual Latency in the Right and Left Ulnar Nerves by Routine Technic.

28 Healthy Subjects

Subject	Sex	Age	(R) ULNAR Wrist - Hypothenar Conduction Dist.	(R) ULNAR Wrist - Hypothenar Conduction Time	(R) ULNAR Above Elbow - Wrist Conduction Velocity	(R) ULNAR Latency	(L) ULNAR Wrist - Hypothenar Conduction Dist.	(L) ULNAR Wrist - Hypothenar Conduction Time	(L) ULNAR Above Elbow - Wrist Conduction Velocity	(L) ULNAR Latency
1.	M.	38	5.4	2.0	68.7	1.21	5.0	2.3	73.7	1.60
2.	F.	20	5.7	2.4	53.0	1.33	5.7	2.5	62.5	1.59
3.	F.	23	5.2	2.4	53.1	1.42	4.9	2.1	51.5	1.14
4.	F.	24	4.5	2.8	59.4	2.04	5.3	3.0	50.7	1.94
5.	F.	36	6.4	2.8	75.5	1.96	7.0	3.0	70.5	2.10
6.	F.	36	6.8	2.8	61.9	1.89	6.4	2.9	61.0	1.84
7.	M.	9	5.2	2.4	74.0	1.94	4.2	2.0	64.3	1.34
8.	M.	30	5.9	3.0	68.0	2.09	6.0	2.9	64.6	1.97
9.	F.	31	6.4	2.8	74.5	1.94	6.8	2.6	73.0	1.67
10.	F.	19	5.0	2.3	68.4	1.48	5.3	2.6	64.1	1.77
11.	F.	15	4.5	2.7	71.3	2.07	5.0	2.6	61.0	1.78
12.	F.	18	4.5	3.0	72.1	2.38	5.0	2.9	61.1	2.08
13.	F.	28	5.4	2.2	61.5	1.32	5.4	2.0	61.0	1.12
14.	F.	19	6.2	2.6	71.0	1.93	6.4	2.5	61.0	1.60
15.	F.	18	5.1	2.6	75.9	1.93	5.2	2.5	64.8	1.69
16.	M.	19	7.0	3.0	59.2	1.82	8.4	3.4	62.6	2.06
17.	F.	8	3.5	1.8	63.6	1.25	3.5	1.9	61.4	1.33
18.	F.	1 3/12	2.8	2.0	96.6	1.73	2.8	1.6	84.2	1.29
19.	M.	11	4.0	2.1	91.7	1.63	4.0	2.0	67.8	1.41
20.	F.	23	5.4	2.8	54.6	1.98	5.3	2.6	58.4	1.53
21.	F.	24	5.0	2.5	55.0	1.60	5.2	2.4	54.0	1.44
22.	F.	20	5.1	2.7	68.6	1.96	5.9	2.5	55.0	1.43
23.	F.	21	5.1	2.6	60.0	1.75	5.0	2.4	61.0	1.58
24.	F.	20	5.5	2.9	67.8	1.54	6.5	2.5	63.6	1.46
25.	F.	21	6.2	2.8	65.6	1.98	6.0	2.5	61.5	1.53
26.	F.	49	6.5	2.0	67.8	1.64	7.0	2.0	55.2	1.74
27.	F.	27	6.2	2.5	52.1	1.31	6.0	2.3	60.0	1.20
28.	M.	34	7.9	2.8	56.0	1.39	7.0	2.8	62.5	1.68
	Total		152.4	71.3	1866.9	48.51	156.2	69.3	1752.0	44.91
	Average		5.44	2.54	66.67	1.73	5.57	2.45	62.39	1.60
	Range		(2.8-7.9)	(1.8-3.0)	(53.0-96.6)	(1.21-2.38)	(2.8-7.0)	(1.6-3.0)	(50.7-84.2)	(1.12-2.10)

TABLE XII

Conduction Time and Conduction Distance for (R) Ulnar and Median Nerves recording from the position of maximum amplitude of action potential on Hypothenar and Thenar following stimulation at Axilla, Above Elbow, Below Elbow, and Wrist.

Subject	Sex	Age	ULNAR								MEDIAN					
			*W - H		*B/E - H		*Ax - H		*A/E - H		*W - T		*Ax - T		*A/E - T	
			**T	**D	T	D	T	D	T	D	T	D	T	D	T	D
1.	F.	24	3.2	6.0	5.8	35.4	7.3	33.4	11.8	53.2	3.4	7.1	11.3	54.2	7.9	33.1
2.	M.	20	3.1	6.8	6.8	27.8	8.1	34.0	11.0	52.6	4.5	8.5	12.0	53.0	9.0	35.6
3.	M.	23	2.8	6.0	6.0	27.0	7.2	32.8	9.8	44.0	3.0	7.4	10.3	50.9	7.8	33.9
4.	F.	21	2.9	6.5	5.8	29.0	6.7	34.0	9.9	54.9	3.0	6.8	10.3	55.0	7.5	33.7
5.	F.	26	2.6	5.0	5.9	23.8	9.7	47.0	7.3	29.7	2.9	7.0	9.8	46.2	6.6	27.0
6.	M.	23	3.4	6.4	7.6	29.3	12.6	56.2	9.7	37.6	4.0	6.5	12.0	55.0	8.6	33.5
7.	M.	42	2.3	6.8	6.2	27.1	10.5	48.3	7.5	32.3	3.9	7.4	10.4	47.9	7.7	31.5
8.	M.	47	2.9	6.5	7.0	26.7	11.5	49.2	8.5	33.0	4.5	7.3	12.0	49.7	9.5	33.6
9.	F.	22	2.4	4.6	5.9	24.8	9.3	48.1	6.8	30.3	3.0	6.0	10.0	48.7	7.8	29.8
10.	F.	23	2.5	5.0	5.5	23.6	9.4	46.7	6.8	29.2	2.8	5.6	9.8	47.9	6.9	28.9
11.	F.	20	2.6	6.7	6.0	26.1	10.2	51.0	8.0	32.9	3.2	7.0	10.2	50.0	7.0	30.4
12.	F.	21	2.2	5.0	5.0	21.6	8.8	43.4	6.5	28.0	3.0	5.6	9.2	32.4	6.5	27.4
13.	M.	42	2.9	5.9	6.4	28.3	10.0	49.9	7.6	34.3	3.5	7.4	10.5	48.4	8.0	31.4
14.	F.	14	2.3	5.8	5.6	25.3	9.2	48.3	7.0	31.2	3.2	5.8	9.4	46.3	7.2	29.2
15.	F.	21	3.3	6.5	6.3	25.8	10.4	50.8	8.0	31.9	3.4	7.7	10.6	51.4	7.6	30.8
16.	F.	22	2.4	5.8	5.0	23.0	8.5	43.6	6.5	28.3	3.0	7.0	8.7	43.0	6.7	27.7
17.	F.	26	3.0	6.1	5.5	25.2	9.2	47.7	6.9	29.7	3.0	6.2	9.1	47.2	6.6	29.0
18.	F.	20	2.8	5.5	6.0	24.0	9.8	46.5	7.0	29.5	3.0	6.4	9.4	46.7	7.0	28.0
19.	F.	21	2.4	5.8	6.0	27.2	10.4	48.3	7.6	32.5	3.0	6.0	10.0	48.4	7.4	31.3
20.	M.	29	2.8	5.3	5.9	25.6	9.4	46.3	7.0	32.1	4.0	6.3	10.0	47.3	8.0	33.3
21.	F.	20	3.0	4.6	6.0	24.2	10.5	46.5	7.0	28.6	3.0	5.2	10.0	45.0	7.0	26.5
Total 21	M-7	527	57.8	122.6	126.2	550.8	198.7	952.0	168.2	735.8	70.3	140.2	215.0	1014.6	158.3	645.6
Average	F-14		2.76	5.84	6.0	26.2	9.44	45.3	8.0	35.0	3.2	6.7	10.2	48.4	7.5	30.7

*Wrist - Hypothenar, Below Elbow - Hypothenar, Axilla - Hypothenar, Above Elbow - Hypothenar
*Wrist - Thenar, Axilla - Thenar, Above Elbow - Thenar.

**Time (msecs)
**Distance (cm.)

TABLE XIII

Conduction Velocities (m/sec) in Segments of the Right Ulnar and Median Nerve

recorded by *Special Technique

Subject	Sex	Age	**Axilla-A/E	(R) ULNAR N. ± HYPOTHENAR A/E-B/E	B/E-W	A/E-W	Residual Latency	(R) MEDIAN N. ± THENAR Axilla-Elbow	Elbow-Wrist	Residual Latency
1	F	24	44.0	57.1	72.0	67.0	2.31	54.5	57.8	2.17
2	M	20	60.7	47.2	56.8	54.5	1.86	59.7	60.5	3.10
3	M	23	66.0	48.3	65.7	60.9	1.81	68.0	66.1	1.87
4	F	21	62.5	55.5	77.5	59.4	1.81	77.5	59.7	1.86
5	F	26	72.0	42.1	57.0	52.6	1.66	60.0	54.0	1.61
6	M	23	62.0	39.5	54.5	49.5	2.09	60.5	58.6	2.90
7	M	42	53.4	40.0	52.0	49.2	0.92	60.0	63.4	2.74
8	M	47	54.0	42.0	49.5	47.5	1.53	64.5	53.2	3.13
9	F	22	71.5	61.1	57.8	58.3	1.61	86.0	49.8	1.80
10	F	23	67.4	43.0	62.0	56.4	1.61	65.5	56.6	1.83
11	F	20	67.3	34.0	57.0	48.9	1.38	62.5	48.9	1.77
12	F	21	56.5	42.6	59.4	51.2	1.23	55.7	62.3	2.11
13	M	42	65.0	50.0	64.0	62.5	1.96	68.0	53.5	2.12
14	F	14	77.8	42.4	59.0	54.0	1.26	77.8	58.4	2.21
15	F	21	78.5	35.9	58.5	55.0	2.12	68.6	55.4	2.02
16	F	22	71.5	35.3	66.2	55.0	1.35	76.5	56.0	1.75
17	F	26	78.3	32.1	76.5	60.5	2.00	70.8	63.4	2.02
18	F	20	60.7	55.0	58.0	57.0	1.83	78.0	54.0	1.82
19	F	21	58.8	33.1	59.5	51.5	1.28	65.8	57.6	1.96
20	M	29	62.5	59.0	65.5	63.8	1.98	64.5	60.7	2.97
21	F	20	51.2	44.0	65.5	60.0	1.85	61.6	53.4	2.03
Total			1341.6	939.2	1293.9	1174.7	35.45	1406.0	1203.3	47.9
Average			63.9	44.24	61.63	55.9	1.69	67.0	57.3	2.18
Range			(44.0-78.5)	(32.1-61.1)	(49.5-77.5)	(47.5-67.0)	(0.92-2.31)	(54.5-86.0)	(48.9-66.1)	9(1.61-3.13)

*All measurements of conduction distance were taken from the position on the muscle from which the highest amplitude of the action potential was recorded.

**Points of stimulation on Ulnar N. were at axilla, just above the elbow, and below the elbow, and wrist; and for the Median N. at the axilla, elbow, and wrist.

	Axilla-A/E	A/E-B/E	B/E-W	A/E-W	Residual Latency	Residual Latency (Median)
Standard Deviation	9.21	8.79	7.29	5.36	.35	.48

P. = .00005

Residual Latency Mean Difference = .49 P. = .0001

TABLE XIV

TEST OF RELIABILITY

Recordings of amplitude of evoked potential from P_1* and P. Max** on Hypothenar Muscle by standard technique on different days, in the same subject.

Subject	Date	Amplitude of evoked potential (mv) P_1	P. Max.	Nerve	Side
1	19-9-62	8.96	8.96	Ulnar	R
	19-9-62	9.06	9.5	Ulnar	L
	20-9-62	8.5	8.5	Ulnar	R
	20-9-62	8.12	8.96	Ulnar	L
	1-11-62	9.3	9.3	Ulnar	R
	1-11-62	9.0	9.6	Ulnar	L
	26-4-63	9.0	9.4	Ulnar	R
	26-4-63	8.23	9.79	Ulnar	L
	18-4-63	8.33	8.64	Ulnar	R
	18-4-63	9.0	9.4	Ulnar	L
	Total	87.5	92.05		
	Average	8.75	9.2		
	Range	(8.12-9.3)	(8.8-9.79)		
	Variation	(± 6.75%)	(± 7.0%)		
2	14-5-62	8.6	9.7	Ulnar	R
	14-5-62	8.64	9.38	Ulnar	L
	1-11-62	10.0	11.0	Ulnar	R
	1-11-62	10.4	11.2	Ulnar	L
	Total	37.64	41.28		
	Average	9.41	10.32		
	Range	(8.6-10.4)	(9.38-11.2)		
	Variation	(± 9.6%)	(± 8.7%)		

* P_1 - Standard Position One.

**P. Max. - Position from which maximum amplitude of evoked potential was recorded.

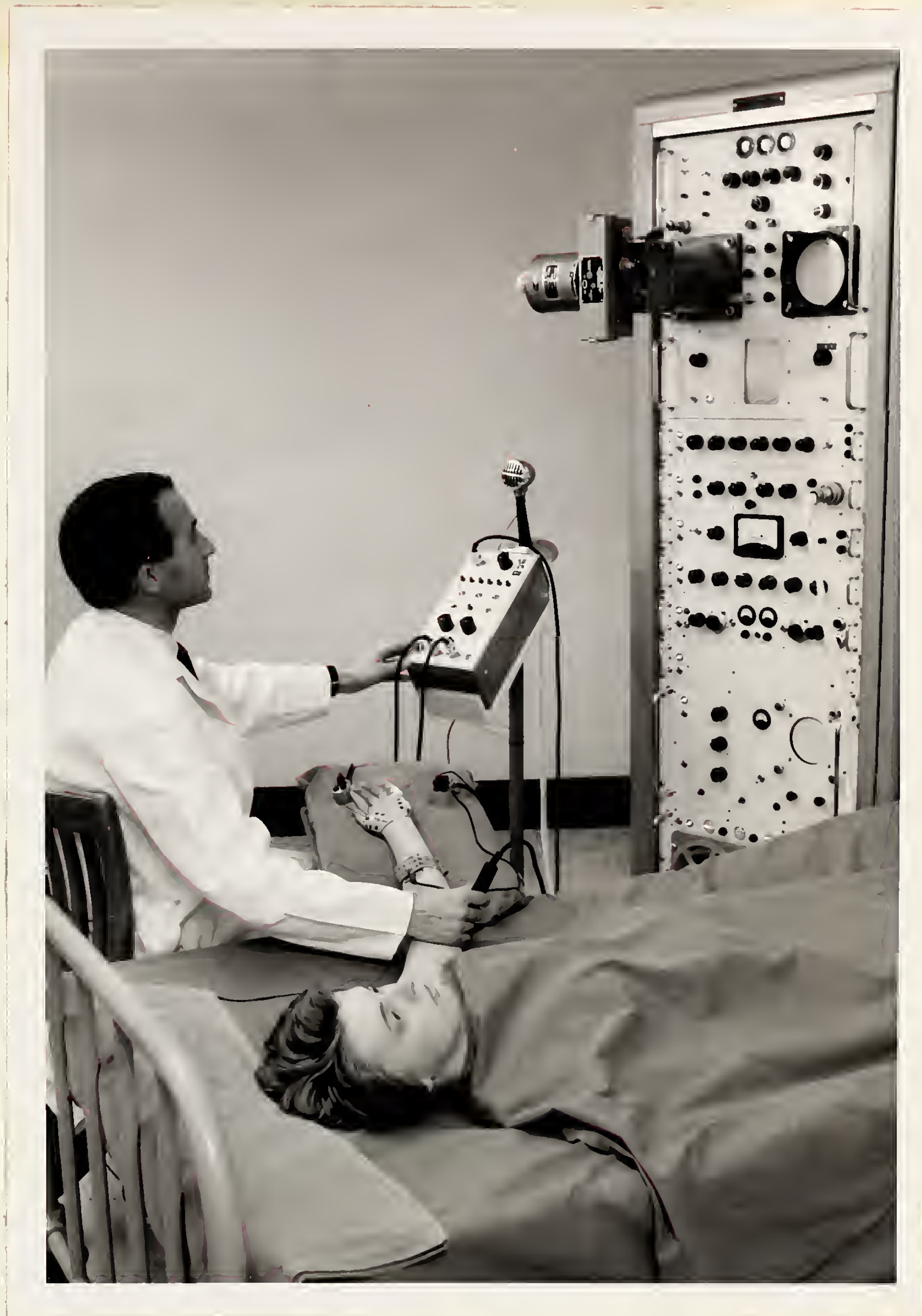
Fig. 1 Shows operator, patient, and electromyograph in position for stimulating ulnar nerve at the elbow and simultaneously recording evoked potentials from both thenar and hypothenar muscles.

Note - (a) Abducted position of arm for easy access to axilla, and marking for nine standard recording positions over hypothenar and thenar.

(b) Three oscilloscopes (1) top left - Cossar camera in front of monitor scope.

(2) top right - viewing scope with identical tracing to camera scope.

(3) storage scope immediately below other two scopes - for permanent and superimposed displays of any one beam, synchronously with other two scopes.



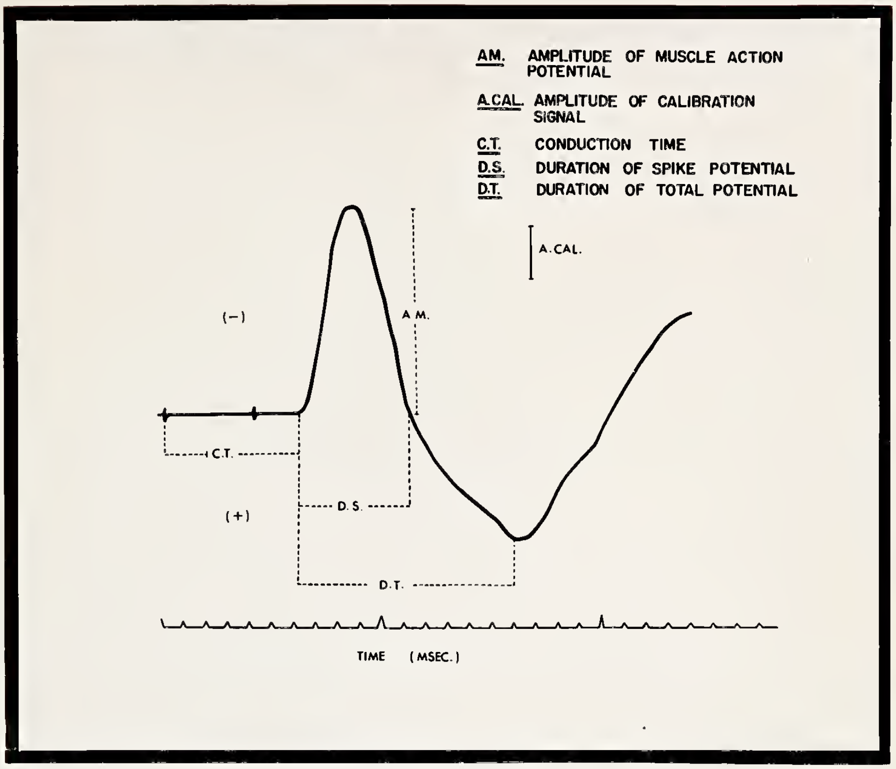


Fig. 2 Measurements of muscle action potential used in present study include amplitude, spike duration, total duration, and conduction time.

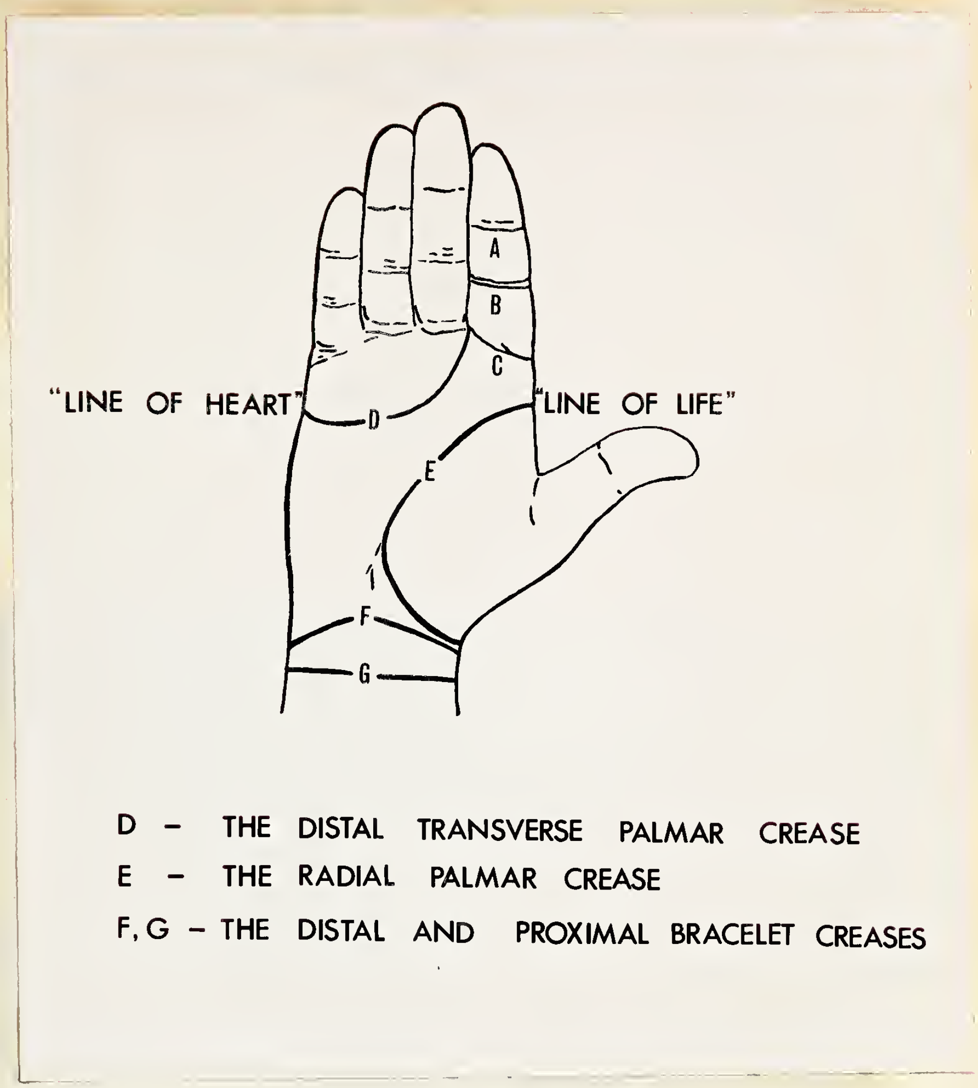


Fig. 3 Surface markings of hand and skin creases used as reference lines for marking out standard positions on thenar and hypothenar muscles.

Fig. 3a Standard positions for locating recording electrodes over the thenar muscles.

Fig. 3b Standard positions for locating recording electrodes over the hypothenar muscles.

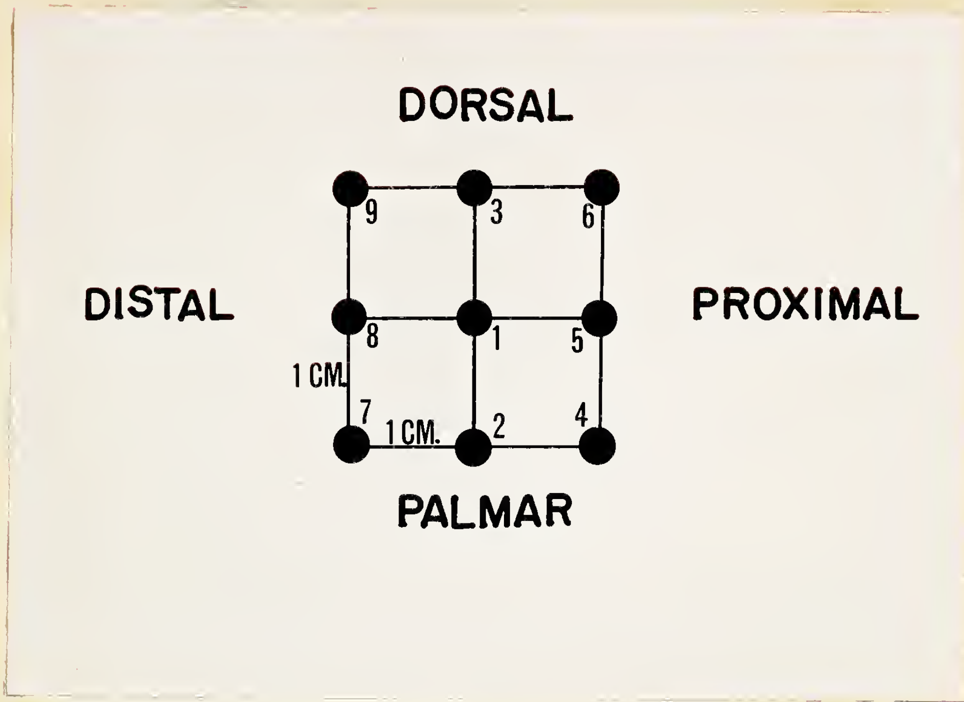


Fig. 3c Diagram of holes cut in rubber template used in marking out nine standard recording positions over hypothenar and thenar muscles.

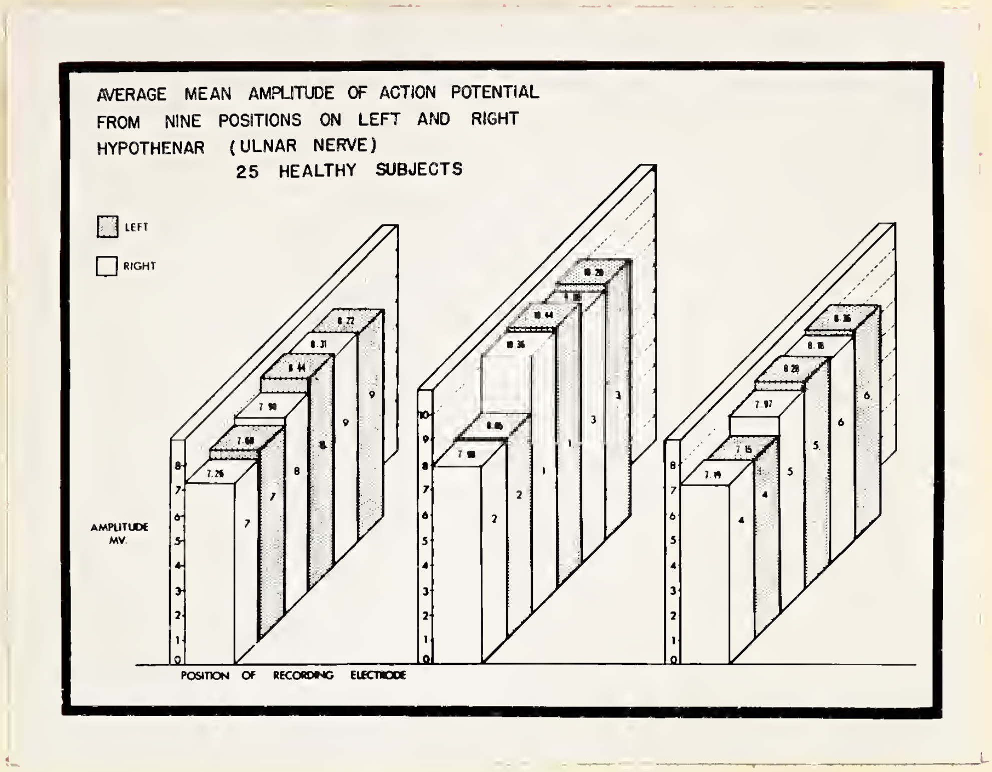


Fig. 4a A histogram of average amplitude of evoked potential related to nine standard positions on hypothenar following stimulation of the ulnar nerve.
Note how amplitude decreases all around $P._1$, but that $P._3$ is nearly as high or higher than any other positions.
The amplitudes for the left and right sides are very similar.

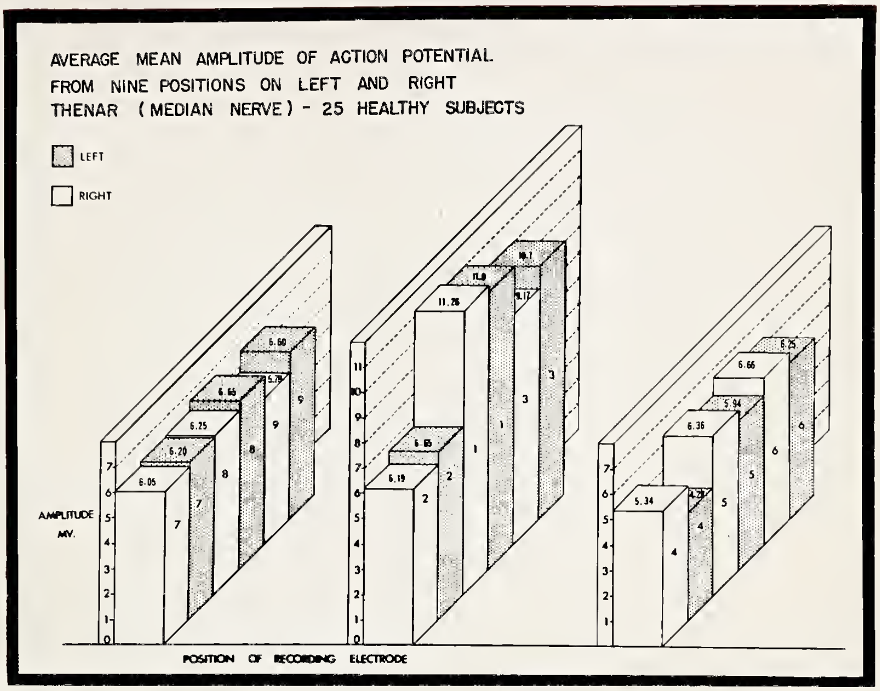


Fig. 4b A histogram of average amplitude of evoked potential related to nine standard positions on thenar, following stimulation of the median nerve. Note how amplitude decreases all around $P._1$, but that $P._3$ is nearly as high and much higher than any other positions.

The amplitudes for the left and right sides are very similar.

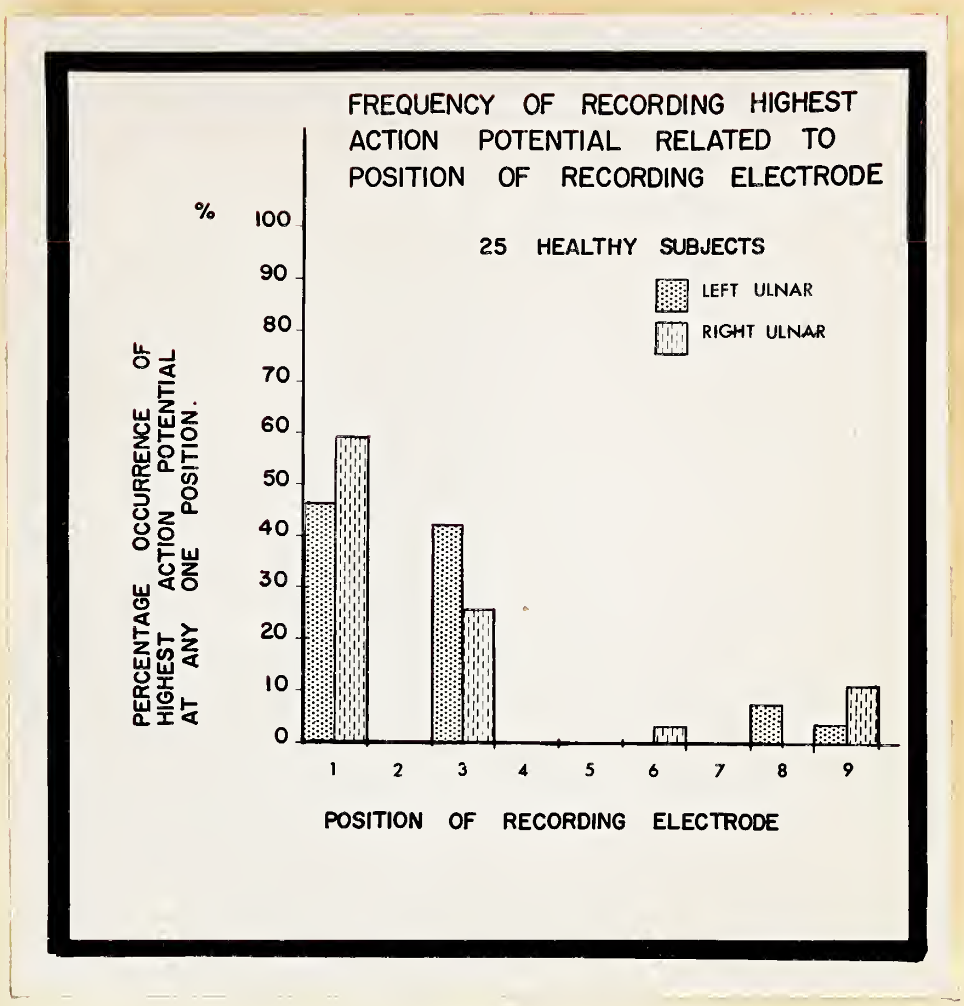


Fig. 5a Frequency of recording highest action potential related to position of recording electrode, from hypothenar following stimulation of ulnar nerve. Note that over 80% of recordings of highest amplitude occur from positions one and three.

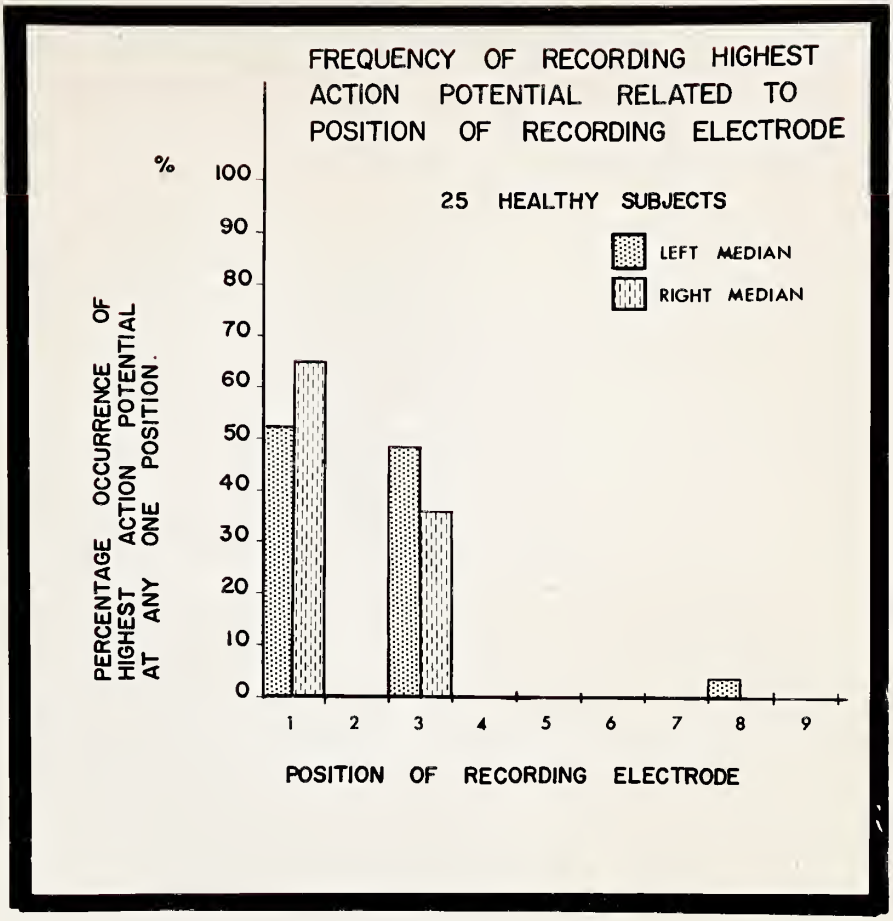


Fig. 5b Frequency of recording highest action potential related to position of recording electrode from thenar muscles following stimulation of median nerve. Note that over 90% of all recordings of highest amplitude occur from positions one and three.

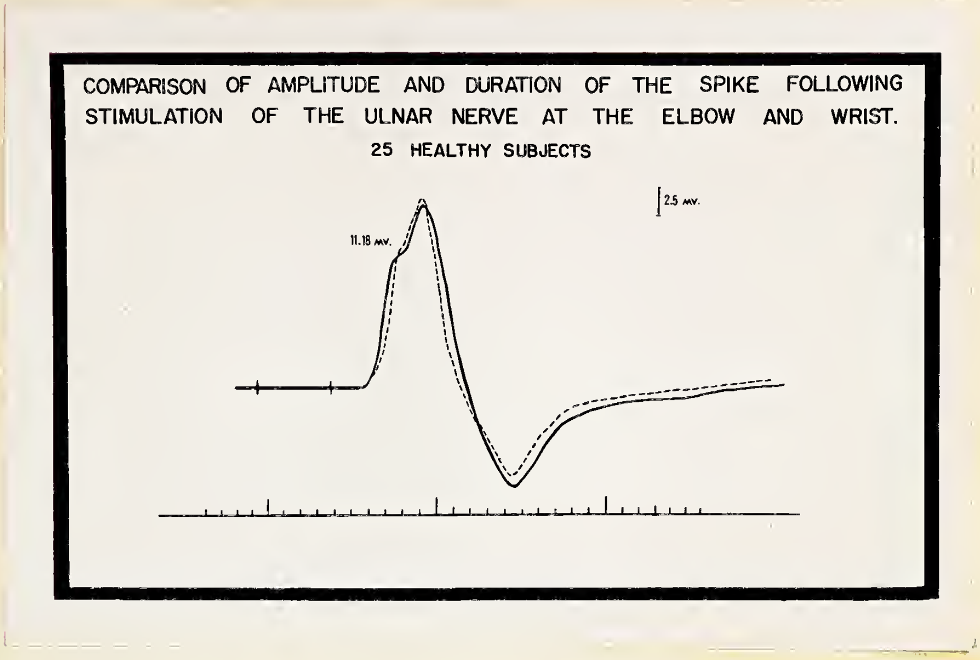


Fig. 6a Diagram of average of evoked potentials recorded from position of maximum amplitude on hypothenar muscles following stimulation of ulnar nerve at elbow and wrist.

Note: Following stimulation at wrist (dashed line) amplitude is slightly higher and duration slightly shorter than following stimulation at elbow (solid line).

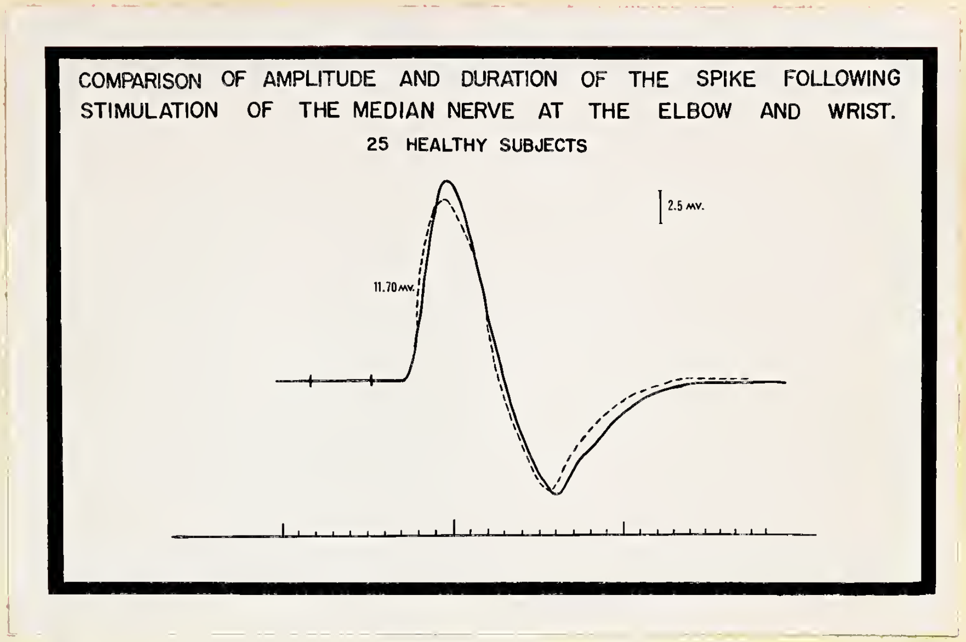


Fig. 6b Diagram of average of evoked potentials recorded from position of maximum amplitude on thenar muscles following stimulation of median nerve at elbow and wrist.

Note: Following stimulation at wrist (dashed line) amplitude is slightly lower and duration slightly shorter than following stimulation at elbow (solid line).

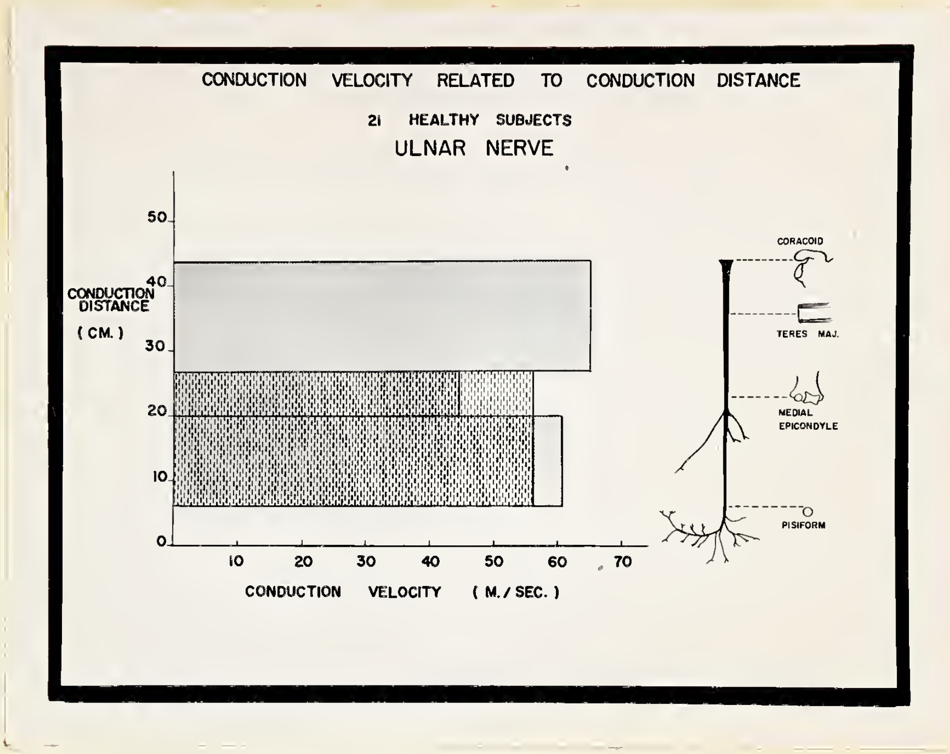


Fig. 7a Average conduction velocity between any two points on ulnar nerve can be read from abscissa. Note: how conduction velocity is fastest in upper arm, which is faster than forearm, and both of which are much faster than for portion where nerve crosses medial epicondyle.

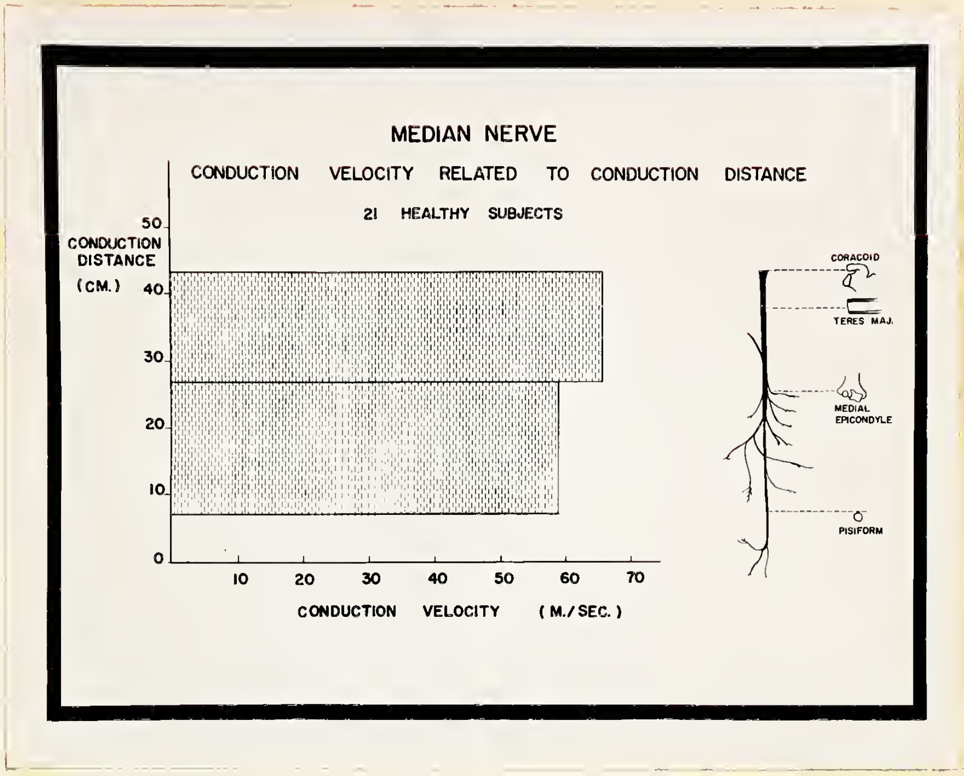


Fig. 7b Note that average conduction velocity for median nerve in upper arm is appreciably faster than for median nerve in forearm.

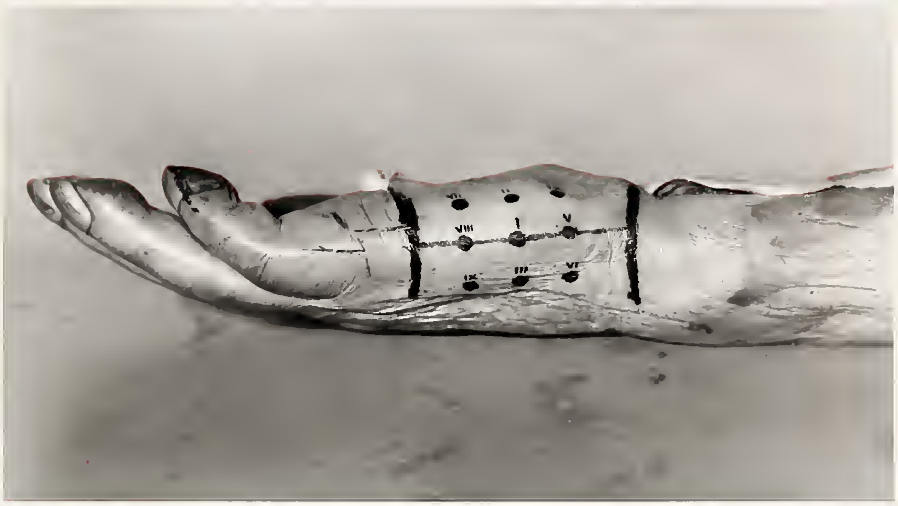


Fig. 8a Hand of cadaver illustrating standard positions for placing recording electrode for finding site of highest action potential following supramaximal stimulation of ulnar nerve.

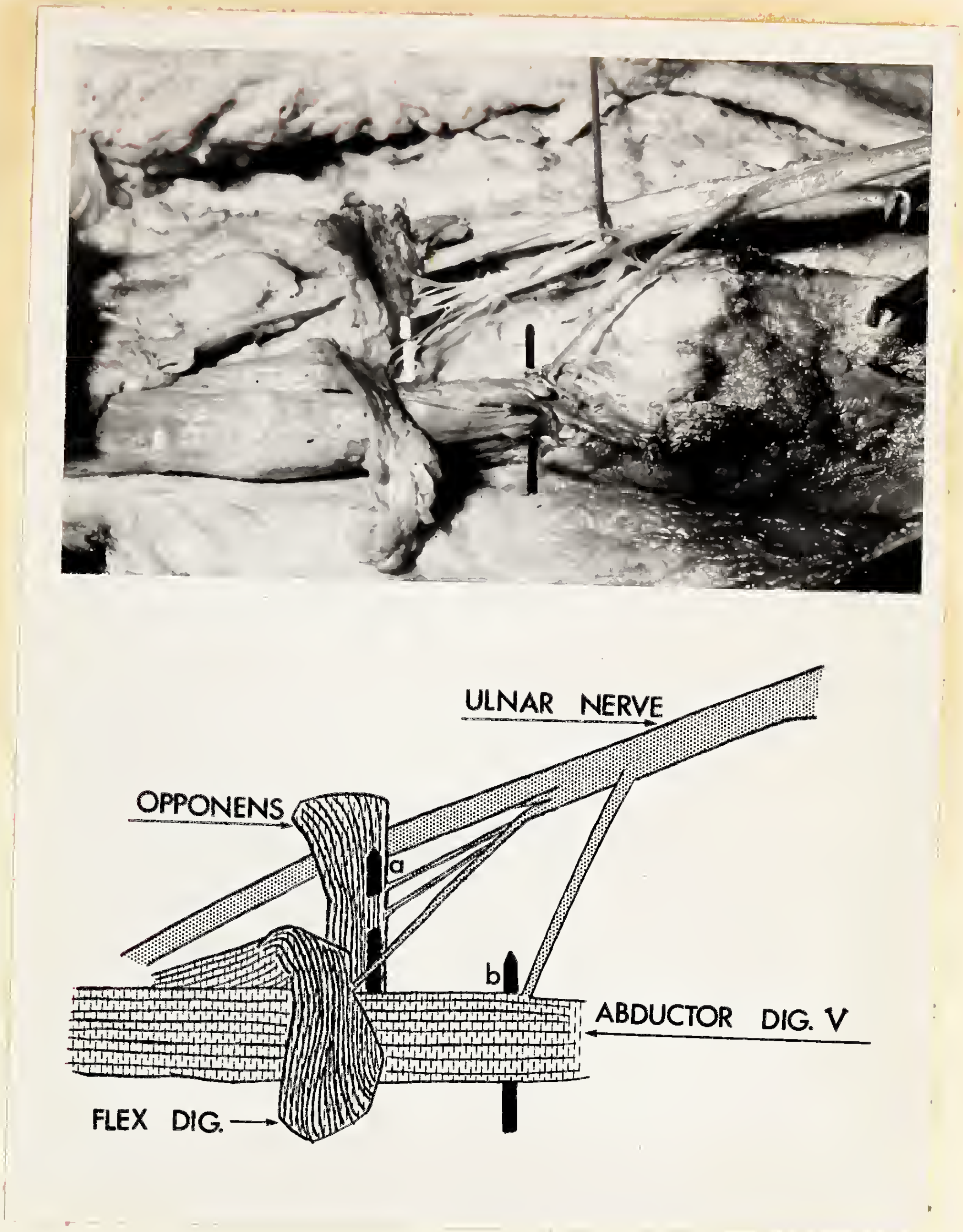


Fig. 8b Illustrating end point of small nerve fibres of ulnar nerve in hypothenar muscles. Pins stuck perpendicular to and through overlying skin at point nearest to end point of nerve in muscle. Note relationship of pins and termination of nerve fibres to positions one and five.

Fig. 8c Ulnar border of hand of cadaver, showing standard recording positions for hypothenar and ulnar nerve. Note white pin at position one corresponds to white pin (Fig. 8b) in opponens digiti quinti at termination of ulnar nerve fibres. Note also black (rimmed) pin at position five corresponds to black pin (Fig. 8b) in abductor digiti quinti at point of termination of nerve fibres.

Fig. 8d Thenar eminence of hand of cadaver showing standard recording positions for thenar and median nerve. Pin has been inserted at point on surface opposite to where majority of median nerve fibres terminate in hand.

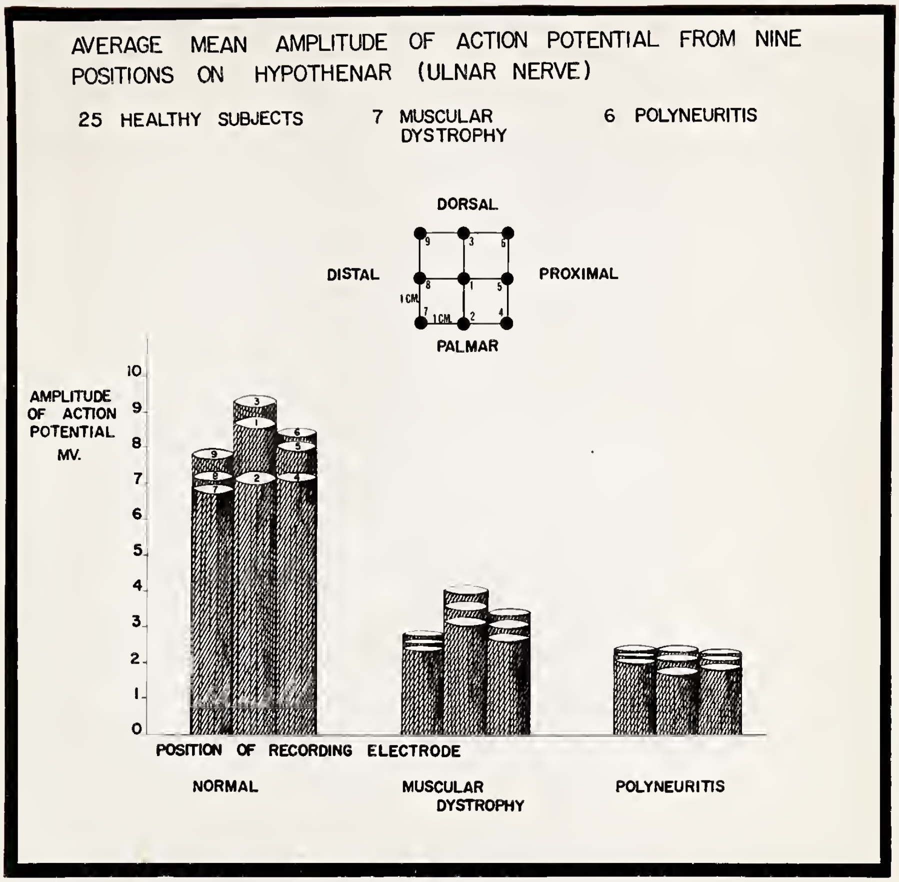


Fig. 9 A histogram relating amplitude of evoked potential to standard recording position on hypothenar muscles following stimulation of ulnar nerve at the elbow. Average results for twenty five healthy subjects, seven patients with muscular dystrophy, and six with polyneuritis. Relative size of amplitudes from each position and each group is correct. However, all recordings are 10 - 20% below normal absolute values because they were made by a special technique with a short time constant on the amplifier.

Fig. 10a Polaroid photograph of skiatron tracing showing difference in amplitude and duration recorded from position of maximum amplitude on adductor pollicis, following stimulation of ulnar nerve when thumb is relaxed and when held in full abduction. Note tracing of higher amplitude and longer duration is where thumb is held in fully abducted position. Calibration one millivolt.

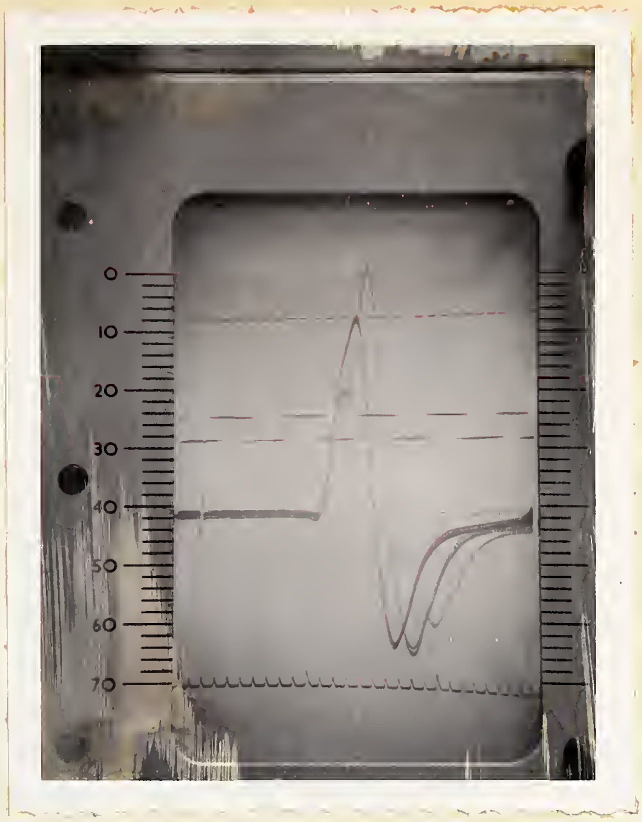


Fig. 10b Polaroid photograph of skiatron tracing showing comparison in amplitude and duration of recording from position of maximum amplitude on adductor pollicis following stimulation of ulnar nerve, and different rates. One second trains of stimuli were given at rates of one per second, three per second, ten per second, and thirty per second. Note at rates of one per second and three per second, there is no change in amplitude or duration, but with ten per second and thirty per second, amplitude gets progressively smaller and duration progressively shorter. Calibration one millivolt.

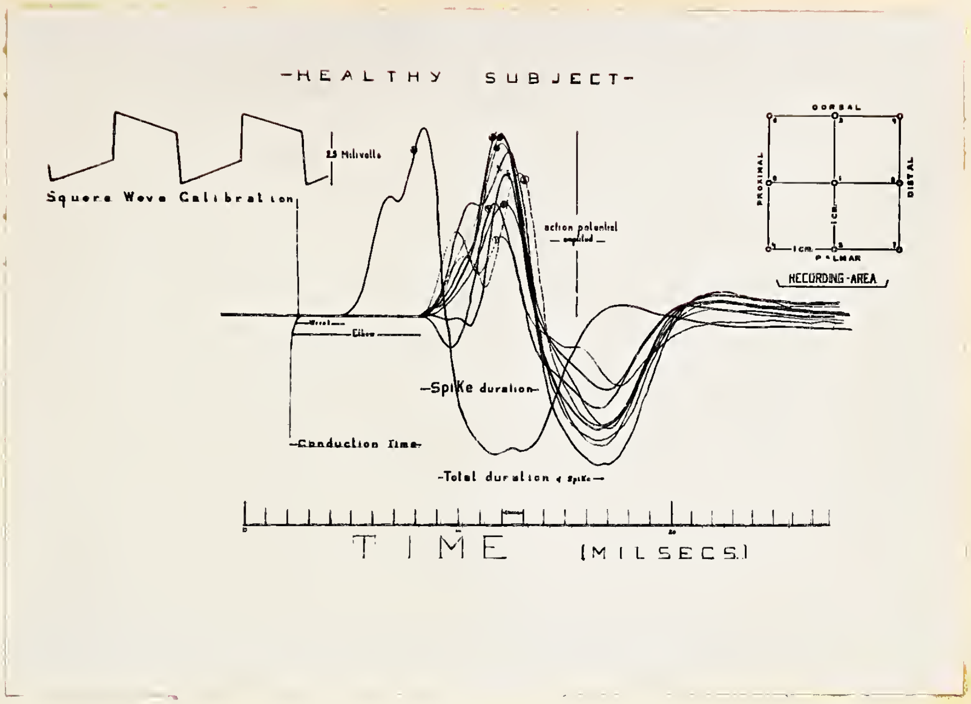


Fig. 11 The superimposed tracing of evoked potentials recorded from nine different positions over the hypothenar muscles following stimulation of the ulnar nerve at the elbow. When the nerve was stimulated at the wrist, the recording electrode was placed in the position of maximum amplitude. Note how the conduction time remains the same regardless of position of the recording electrodes when stimulus was at the elbow.